Learning Linguistic Disjunction

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Abstract

Research on word learning has discovered constraints, cues, and mechanisms that can help a language learner create successful word-meaning mappings. So far, the literature has mainly focused on the acqusition of content words such as nominals and verbs, leaving functional elements largely understudied. The current study fills this gap by investigating the constraints, cues, and mechanisms that can aid the acqusition of disjunction. Based on naturalistic recordings of parent-child interactions, we argue that children may learn to interpret a disjunction by partitioning their form-meaning mappings based on salient cues that accompany it in child-directed speech. In order to better understand the distribution of *or* in parents' and children's speech, we first collected statistics of its use across speakers, ages, and contexts. The results show that children start producing *or* between 18-30 months and by 42 months their productions plateau at a constant rate. We also find that the most likely interpretation of *or* in child-directed speech is exclusive disjunction. However, exclusive interpretations correlated with a rise-fall intonation, and logically inconsistent propositions. In the absence of these two cues, *or* was commonly not exclusive. Our computational modeling shows that a hypothetical learner can successfully interpret an English disjunction by mapping forms to meanings after partitioning the input using the set of salient cues (cue-based) in the context of the utterance (context-dependent). We discuss the implications of our work for current theories of word learning.

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Introduction

Word learning is commonly construed as the process of detecting a word form, hypothesizing candidate meanings, and mapping the form to its intended meaning (Clark, 1993, p. 43). While this process sounds straightforward, it is a challenging problem because each word is in theory compatible with innumerable candidate meanings (Quine, 1960). Imagine someone pointing to a fish tank and saying *mahi* in a foreign language. What could *mahi* mean? Maybe "look", "pretty", "fish", "swim", or a myriad of other concepts. However, previous research suggests that children solve the form-meaning mapping problem using a variety of learning biases, cues, and mechanisms. For example, early word learning favors whole-object concepts over object parts, taxonomic concepts over thematic ones, and one-to-one mappings over many-to-one or one-to-many mappings (Clark, 1987, 1993; Markman, 1990; Markman & Hutchinson, 1984; Markman & Wachtel, 1988). Furthermore, social cues like pointing or eyegaze can help direct learners' attention to aspects of experience that words refer to (Baldwin, 1993; Tomasello, 2003), and morphsyntactic cues on nouns, adjectives, or verbs can help learners restrict their hypotheses to the domain of objects, properties, or actions (Brown, 1957; Gleitman, 1990). Finally, the form-meaning mapping mechanism can also be part of the solution. While each learning instance of a word in isolation may be compatible with many candidate meanings, a mapping mechanism that aggregates candidate meanings across multiple situations reduces this indeterminacy substantially (Siskind, 1996; Smith, Smith, & Blythe, 2011; Yu & Smith, 2007). For example if *mahi* is uttered in the context of a fish tank, drawing a fish, and eating fish, we can become more certain that it means "fish". We can call the set of biases, cues, and mechanisms that result in successful acquisition of a word like *mahi*, a word learning strategy.

Since the lexicon is made up of diverse classes of words, different strategies may be needed for each class. In other words, the combination of biases, cues, and mapping mechanism that works for one class, may not necessarily work for another. Consider the most basic and broadest distinction in the lexicon: that of content and function words. Content words consist of nouns, verbs, adjectives, and some adverbs. They encode relatively bigger chunks of meaning and often refer to aspects of everyday experience like objects, properties, and actions. On the other hand, function words like *or*, *not*, *can*, and *the* have very abstract meanings. They are the nuts and bolts that connect content words together and their meanings are best understood in terms of the combinatorial and compositional role they play in building the overall interpretation of the sentence. While there has been considerable research on learning content words, word learning strategies for function words remain relatively understudied. Many of the biases, cues, and mechanisms discussed before are more suitable for content words than function words. For example social cues such as pointing and eyegaze that aid the acquisition of concerete nominals, do not seem to be as helpful when it comes to words like *or* and *not*. Similarly, whole-object or taxonomic constraints do not extend to function words in a straighforward manner. In order to have a general solution to the form-meaning mapping problem, we need to study biases, cues, and mechanisms that can solve the form-meaning mapping problem for function words.

Quine (1960, p. 12) proposed three different form-meaning mapping strategies that apply to different words and word classes to varying degrees. Follwoing Quine's terminology, we call them "isolated" mapping, "context-dependent" mapping, and "description" mapping. Isolated mapping refers to the case of hearing a word (more accurately a linguistic form) and mapping it to a hypothesized meaning isolated from its linguistic context. For example hearing *mahi* (as an utterance or part of an utterance) and mapping it to the concept "fish". Concrete nominals are prototypical examples of isolated mapping. On the other hand, context-dependent mapping is learning a word "contextually, or by abstraction, as a fragment of sentences learned as wholes". It is important to emphasize that context here refers to the linguistic context. Quine suggested that all words are to some degree learned in a context-dependent way but "prepositions, conjunctions, and many other words, are bound to have been learned only contextually; we get on to using them by analogy with the ways in which they have been seen to turn up in past sentences". According to Quine, learning such words requires attention to the linguistic context of use. Finally, "description mapping" refers to cases where a word is defined explicitly using other words, similar to a dictionary entry. Quine points out that the meaning of a word such as "molecule" is mapped to a linguistic description (i.e. definition). Under the Quinian theory, word learning starts with isolated mapping and slowly increases its reliance on context-dependent mappings, until finally many words are learned via linguistic descriptions or definitions (see Gleitman, Cassidy, Nappa, Papafragou, & Trueswell, 2005 for a similar view with emphasis on the role of syntactic structure). Given that function words are hypothesized to be learned primarily using the context-dependent strategy, studying linguistic cues that help solving their mapping is a crucial part of their acquisition story.

This paper focuses on the acquisition of linguistic disjunction, and proposes a context-dependent strategy for learning the word *or* in English. Disjunction is a foundational logical concept and has played a major role in advancing theories of formal semantics and pragmatics. The use of a disjunction word like *or* often gives rise to complex implications such as inclusivity, exclusivity, ignorance, and free-choice (Aloni, 2016). Explaining how *or* can give rise to a diverse set of inferences has been a major source of insight into human semantic and pragmatic competence in the past half a century. Furthermore, disjunction has presented theories of language acquisition with a learning puzzle. While experimental studies have found that children undertand the inclusive meaning of disjunction (Crain, 2012; Jasbi & Frank, 2017 among others), research on child-directed speech has shown that the majority of examples children hear are actually exclusive (Morris, 2008). How can children learn the inclusive meaning of *or* if they rarely hear it? We argue that this puzzle arises because of an assumption that the word *or* is mapped to its meaning using an isolated mapping strategy used for content words. We show that a context-dependent strategy for mapping *or* provides a straightforward solution to the puzzle of learning disjunction as well as a general solution for learning words that are polysymous or can give rise to multiple interpretations. In the next two parts of this section, we first summarize previous work on the acquisition of disjunction, and then present our account which builds on this rich literature.

Previous Studies

Morris (2008) investigated the spontaneous productions of *and* and *or* in the speech of parents and their children between the ages of 2;0 and 5;0. He used 240 transcriptions from the CHILDES database and analyzed each connective with respect to its frequency, sentence type, and meaning (or use). The study found that overall, *and* was approximately 12.8 times more likely to be produced than *or*. The connective *and* appeared predominantly in statements (more than 90% of the time) while *or* was most common in questions (more than 85% of the time). Children started producing *and* at 2 and *or* at 2.5 years of age.

Regarding the meaning of the connectives, Morris (2008) adopted a usage-based (item-based) approach (Levy & Nelson, 1994; Tomasello, 2003) and predicted that children start producing connectives with a single "core meaning" (also referred to as "use" or "communicative function"). He suggested that for their core meanings, *and* and *or* are mapped to their most frequent interpretations in child-directed speech. Children acquire the less frequent interpretations of these connectives as they grow older, although the exact mechanism for learning the less frequent interpretations was not discussed. Morris found that children started producing *and* as conjunction at 2, and *or* as exclusive disjunction at 2.5 years of age. He argued that in line with the predictions of the usage-based account, these two meanings are also the most frequent meanings in parents' speech. For disjunction, 75-80% of the *or*-examples children heard recevied an exclusive interpretation. Finally, as children grew older, they started using connectives to convey additional meanings such as inclusive disjunction for *or* and temporal conjunction for *and*. Overall in adult speech, the inclusive use of *or* was extremely rare, and children barely produced it even at age 5. Morris (2008) argued that the development of connectives conforms to the predictions of a usage-based account and that in the first five years of children's development, the (core) meaning of disjunction is exclusive.

However, a series of experimental studies have found that preschool children are more likely to interpret *or* as inclusive in a variety of linguistic contexts such as negative sentences (Crain, Gualmini, & Meroni, 2000), conditional sentences (Gualmini, Crain, & Meroni, 2000), restriction and nuclear scope of the universal quantifier *every* (Chierchia, Crain, Guasti, Gualmini, & Meroni, 2001; Chierchia et al., 2004), nuclear scope of the negative quantifier *none* (Gualmini & Crain, 2002), restriction and nuclear scope of *not every* (Notley et al., 2012a), and prepositional phrases headed by *before* (Notley et al., 2012b). These studies suggest that at least in declarative sentences, the inclusive interpretation of *or* emerges earlier than the exclusive interpretation.

The findings of these studies and Morris (2008) give rise to a paradox: how can children learn to interpret linguistic disjunction as inclusive, if they rarely hear it as inclusive? One way to address this paradox is logical nativism (Crain, 2012; Crain & Khlentzos, 2008, 2010). It proposes that the language faculty constrains the connective meanings entertained by the learner to those used in classical logic: negation, conjunction, and inclusive disjunction. Crain (2012) considered it unlikely that children learn the meaning of *or* directly from the examples they hear in adult usage. Instead, he argued that children rely on an innate knowledge that the meaning of disjunction words in natural languages must be inclusive. In other words, upon hearing a connective word, children consider inclusive disjunction as a viable candidate for its meaning but not exclusive disjunction. In this account, the exclusive interpretation emerges as part of children's pragmatic development after they have mastered the inclusive semantics of disjunction.

While logical nativism addresses the paradox of learning disjunction, it does not provide an explanation for cases where children interpret disjunction as exclusive. Morris (2008) reported that in his study, the vast majority of children used *or* in its exclusive sense. This is not expected if preschool children consider disjunction to be inclusive. Second, other experimental studies, especially those testing disjunction in commands, find that preschool children interpret it as exclusive (Braine & Rumain, 1981; Johansson & Sjolin, 1975). For example, in response to a command such as "give me the doll or the dog", children as young as three- and four-years-old give one of the objects and not both. In its current version, the nativist account does not explain such cases.

Figure 1 summarizes the usage-based and nativist approaches to the acquisition of disjunction. The major difference between them is their assumptions on the learners' semantic hypothesis space. The usage-based account does not hypothesize any a priori constraints and allows a wide array of meanings to be available for mapping, including different flavors of conjunction such as "temporal conjunction" (e.g. She brushed her teeth and (then) went to bed) and "explanatory conjunction" (e.g. You hit Kim and that is not OK!). The nativist account places a constraint on the hypothesis space and limits it to binary logical connectives of standard propositional logic: inclusive disjunction, conjunction, and material implication. Neither accounts use cues. Both accounts assume isolated mapping and agree that the input favors the exclusive interpretation of disjunction. The usage-based account predicts that children map *or* as exclusive disjunction in preschool years while the nativist account predicts that *or* is mapped as inclusive disjunction.

Current Study

In this study, we provide an alternative solution to the paradox of learning disjunction. The main claim of this paper is that child-directed speech contains cues that accompany a linguistic disjunction and if a learner applies a context-dependent mapping strategy, they can successfully learn to interpret a disjunction as exclusive or inclusive. We support this

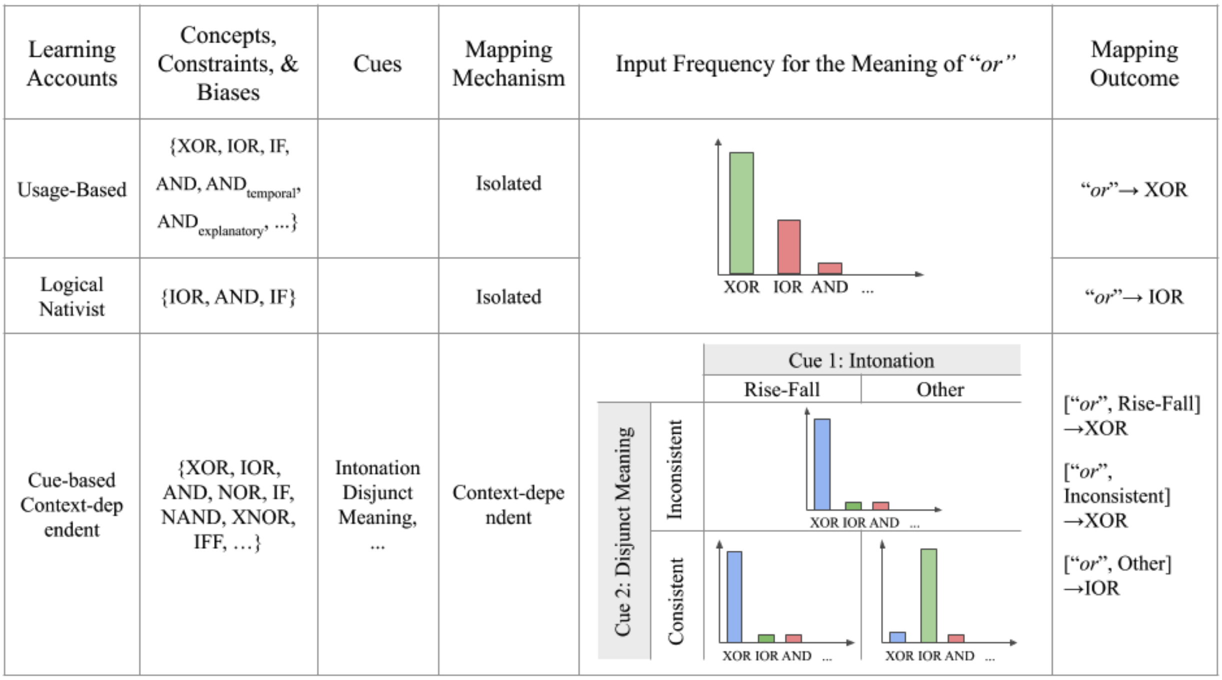

Figure 1. Summary of the usage-based, logical nativist, and cue-based context-dependent approaches to the acquisition of disjunction.

hypothesis using three studies. Study 1 presents the distribution of disjunction and conjunction in parents' and children's speech and addresses the following questions: how often do children hear and produce *or*? and when do they start producing it? Using a large corpus of parent-child interactions, we found that children heard 1-2 examples of *or* in every thousand words parents produced. They started producing it themselves between 18-30 months, and by 42 months they reached the rate of one *or* per thousand words. Studies 2 and 3 provide support for the two parts of our main claim: first the presence of cues, and second their utility in learning. In study 2, we asked: what interpretations can *or* have in child-directed speech? We annotated examples of *or* and found that its most likely interpretation in child-directed speech was exclusive disjunction, as Morris (2008) had concluded. However, we also found that exclusive interpretations correlated strongly with two cues: rise-fall prosody, and logically inconsistent propositions connected by *or*. In the absence of these cues, *or* was most likely non-exclusive. In our third study, we asked if it is possible to learn the correct interpreations of a disjunction from these cues. Using the annotation data of study 2 and a supervised learning task, we showed that a decision-tree classifer can use prosody and consistency of propositions to predict its interpretation with high accuracy.

Based on the results of our studies, we propose a new account for children's acquisition of disjunction. Figure 1 shows the summary of this account which we call "cue-based context-dependent mapping" of disjunction. It is inspired by the usage-based and nativist accounts of disjunction as well as Quine's theory of word learning. Similar to the nativist account, we assume that the semantic hypothesis space includes binary logical relations. However, we do not constrain the hypothesis space further and do not bias the learning towards any particular binary meaning. We will show that the cues available in the linguistic input will do that for us. Similar to usage based proposals, our account relies on the information in the learner's input to distinguish between exclusive and inclusive uses of disjunction. Following Quine's suggestion for mapping function words, we use a mapping mechanism that takes the linguistic context of the function word *or* into consideration. Instead of mapping *or* directly to the most frequent interpretation in the input, our context dependent mechanism partitions the input using a set of cues that designate the linguistic context of use. Mapping is done based on the cues that accompany the connective word. In General Discussion, we discuss our account in the broader context of current world learning theories.

Production Analysis

In our first study, we looked at the frequencies of *or* and *and* in a corpus collection of parent-child interactions (CHILDES) with 14,159,609 tokens. This is a considerably larger corpus than previously used and allows us to measure developmental change in children's production of disjunction more accurately. To account for the role of syntactic development, the conjunction word *and* was used as a control for *or*.

Methods

For samples of parents' and children's speech, we used the online database childes-db and its associated R programming package `childesr` (Sanchez et al., 2018). Childes-db is an online interface to the child language components of TalkBank, namely CHILDES (MacWhinney, 2000) and PhonBank. Two collections of corpora were selected: English-North America and English-UK. All word tokens were tagged for the following information: 1. The speaker role (mother, father, child), 2. the age of the child when the word was produced, 3. the type of the utterance the word appeared in (declarative, question, imperative, other), and 4. whether the word was *and*, *or*, or neither.

Exclusion Criteria. The collection had an initial 16,179,076 tokens. First, tokens that were coded as unintelligible were excluded (N = 290,119). Second, tokens that had missing information on children's age were excluded (N = 1,042,478). Third, tokens outside the age range of 1 to 6 years were excluded (N = 686,870). We were interested in the 1 to 6 years old age range and there was not much data outside this age range. After these exclusions, the collection had 14,159,609 from 504 children and their parents .

Procedure. Each token was marked for the utterance type that the token appeared in. This study grouped utterance types into four main categories: "declarative", "question", "imperative", and "other". Utterance type categorization followed the convention used in the

TalkBank manual. The utterance types are similar to sentence types (declarative, interrogative, imperative) with one exception: the category "question" consists of interrogatives as well as rising declaratives (i.e. declaratives with rising question intonation). In the transcripts, declaratives are marked with a period, questions with a question mark, and imperatives with an exclamation mark. It is important to note that the manual also provides terminators for special-type utterances. Among the special type utterances, this study included the following in the category "questions": trailing off of a question, question with exclamation, interruption of a question, and self-interrupted question. The category imperatives also included "emphatic imperatives". The rest of the special type utterances such as "interruptions" and "trailing off" were included in the category "other".

Results

Overall, *and* was about 10 times more likely to occur in parents' speech than *or*. More specifically, *and* occurred 15 times and *or* only 1.5 times per 1000 words. Children produced *and* at the same rate as their parents but produced *or* at a considerably lower rate, only 0.5 per thousand words (Figure 2, Left). The developmental trend showed that between 12 to 72 months, production of *and* in parents' speech varied between 10 to 20 per thousand words (Figure 2, Right). Children started producing *and* between 12 and 18 months, and showed a sharp increase in their production until they reached the parent level between 30 to 36 months of age. Their productions stayed close to the parents' production level between 36 and 72 months, possibly surpassing them at 60 months – although due to the small amount of data after 60 months we should be cautious with our interpretation of the trend there.

The production of *or* for parents was 1 to 2 per thousand words. Children started producing *or* between 18 to 30 months, steadily increasing their productions until they got close to 1 *or* per thousand words at 48 months (4 years). Their productions plateaued and stayed at this rate until 72 months (6 years). Children's productions of *or* was different from

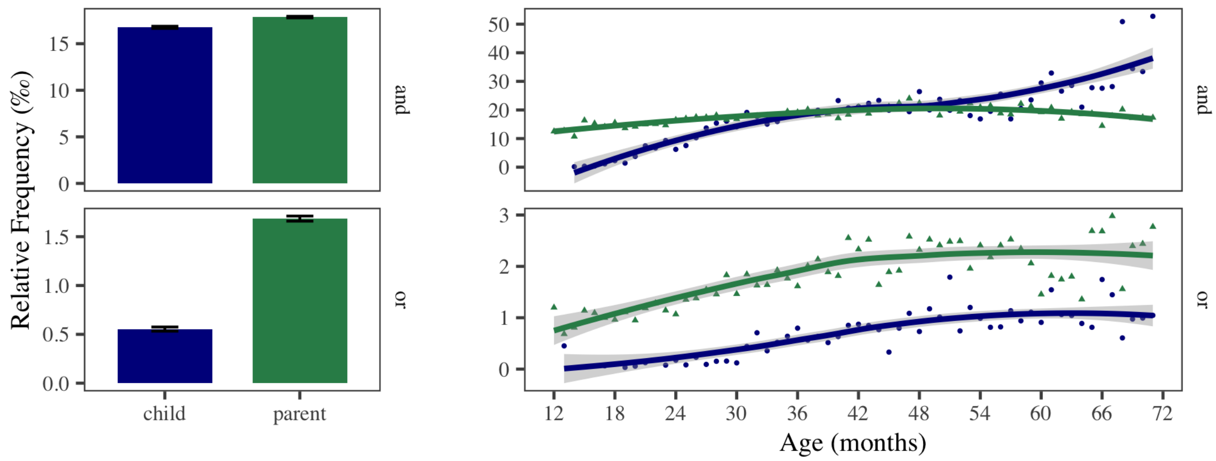

Figure 2. Left: The relative frequency of *and/or* (per mille) in the speech of parents and children. 95% binomial proportion confidence intervals calculated using Agresti-Coull's approximate method. Right: The monthly relative frequency of *and/or* in parents and children's speech between 12 and 72 months (1-6 years).

their production of *and* and parents' production of *or*. Children started producing *or* around 6 months later than *and*. Second, while children's *and*-productions showed a steep rise over a year and reached the parent level around 30 months, their *or*-productions rose slowly and did not reach the parent level even at 6 years of age.

What factors cause these differences? Previous research has discussed two possibilities: frequency and conceptual complexity (Morris, 2008). First, *and* is a far more frequent connective than *or*. Goodman, Dale, and Li (2008) argue that within the same syntactic category, words with higher frequency in child-directed speech are acquired earlier. The conjunction word *and* is at least 10 times more likely to occur than *or* so earlier acquisition of *and* is consistent with the effect of frequency on age of acquisition. Second, research on concept attainment and boolean concept learning has suggested that conjunction is easier to conjure and possibly acquire as a concept than disjunction (Feldman, 2000; Neisser & Weene, 1962; Piantadosi, Tenenbaum, & Goodman, 2016; Shepard, Hovland, & Jenkins, 1961). Therefore, it is possible that children discover the concept that corresponds to the meaning

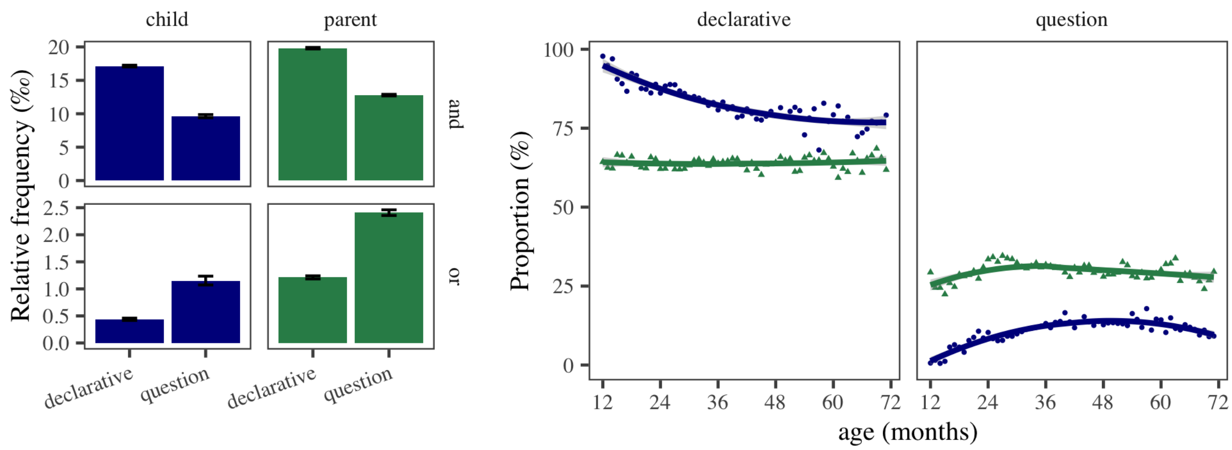

Figure 3. Left: Relative frequency of *and/or* (per mille) in declaratives, imperatives, and interrogatives for parents and children. Right: Percentage of declaratives to questions in parent-child interactions by age.

of *and* faster and start to produce it earlier, but they need more time to concieve of the concept corresponding to the meaning of *or*.

Here we add a third possibility: that the developmental difference between *and* and *or* is partly due to their different usages. Parent-child interactions are not symmetrical and what parents would like to communicate to children is different from what children would like to communicate to parents. This asymmetry can result in different distribution of speech acts between parents and children and consequently functional elements that constitute them. Here we present evidence that suggests *or* is affected in this way.

First, we found that *or* was more likely to occur in questions than in declaratives (Figure 3, Left). This is in contrast to *and* which was more likely to occur in declaratives. Second, parents asked more questions from children than children did from parents, and children produced more declaratives than parents (Figure 3, Right). In fact, questions had their own developmental trajectory, emerging in the second year of children's lives and reaching a relatively constant rate of about 15% of children's utterances in their fourth year.

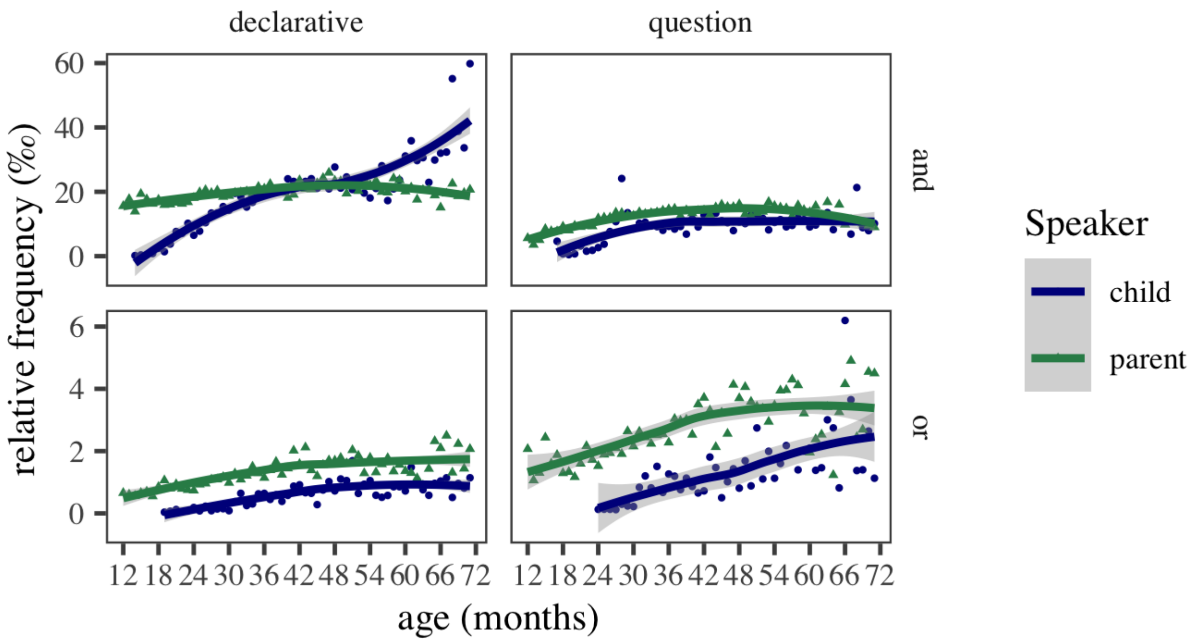

Figure 4. Relative frequency of *and/or* in declaratives and questions for parents and childern between the child-age of 12 and 72 months (1-6 years).

However, parents produce a constant rate of questions which is about 25% of their utterances. Therefore, parent-child interaction provides more opportunities for parents to ask questions and produce *or*, than children.

Figure 4 shows the developmental trends for the relative frequencies of *and* and *or* in questions and declaratives. Comparing *and* in declaratives and questions, we see that the onset of *and* productions were slightly delayed for questions. But in both declaratives and questions, *and* productions reached the parent level around 30 months (2.5 years). For *or*, we see a similar delay in questions compared to declaratives. Children started producing *or* in declaratives at around 18 months but they started producing *or* in questions at 24 months. Production of *or* increased in both declaratives and questions until it reached a constant rate in declaratives between 48 and 72 months. The relative frequency of *or* in questions continued to rise until 60 months. Comparing Figure 2 and Figure 4, children were

Table 1

Estimated cofficients for the linear model with children's age, speaker (child vs. parent), utterance type (declarative vs. question), and their interactions as predictors. Relative frequency of disjunction production was the dependent variable.

Coefficients	Estimate	Std. Error	t value	$Pr(>\lvert t\rvert)$
age	0.02	0.01	3.54	0.00
question	-0.77	0.39	-1.96	0.05
parent	0.72	0.32	2.24	0.03
age*question	0.03	0.01	3.96	0.00
age*parent	0.00	0.01	0.21	0.83
question*parent	1.40	0.48	2.91	0.00
age*question*parent	-0.01	0.01	-1.30	0.20

closer to the adult rate of production in declaratives than questions.

To test these observations more formally, we used a linear regression model with the relative frequency of *or* as the dependent variable and children's age, speaker (child vs. parent), utterance type (declarative vs. question), and their interactions as predictors. The intercept was set to children's productions in declaratives. Table 1 presents the coefficient estimates of the model. Overall, the model suggests that parents and children produced more *or* as children grew older and parents produced more instances of *or* than children. However, the increase in production of *or* was more steep in questions. The largest significant effect was the interaction of speaker and utterance type. Parents produced disjunctions more frequently in quesions than in declaratives. These results are consistent with the hypothesis that frequency and distribution of *or* is partly affected by the development of questions in parent-child interactions.

Conclusion

In a large-scale quantitative analysis of parents and children's productions of *and* and *or*, we found that children started producing *and* in the second year of their lives, and quickly reached their parents' rate of production by two and a half. Their production of disjunction was delayed by six months on average: they started producing *or* between 1.5 and 2.5 years of age, and around 3.5 years, they reached a relatively constant rate of production below that of their parents. We mentioned two possible causes for disjunction's delay and lower rate of production discussed in previous literature, namely the higher frequency of conjunction and the conceptual and mapping complexity of disjunction. We added a third cause, the asymmetry in speech acts produced by parents and children. We showed that parents produced more questions than children, and that *or* was more likelly to occur in questions. Therefore, parents' speech contained more *or* partly due to the fact that parents asked more questions.

Data Annotation

In this study we selected a subset of connective examples in child-directed speech from study 1 to closely examine their interpretations. Research in formal semantics has shown that the interpretation of disjunction depends on several factors including prosody (Pruitt & Roelofsen, 2013), logical consistency of the disjuncts (Geurts, 2006), presence or absence of modals or negation, and pragmatic reasoning (Grice, 1989). Inspired by research in formal semantics and pragmatics, we annotated examples of disjunction for the interpretation they received, as well as potential cues such as the logical consistency of the disjuncts, the utterance type, the intonation type, syntactic category of the disjuncts, communicative function of the utterance, and presence or absence of negative or modal morphemes. Our main finding is that in child-directed speech, exclusive interpretations of *or* correlate with rise-fall prosody and logically inconsistent propositions. In the absence of these two factors, *or* is most likely "not exclusive". Therefore, these cues could be informative for children with respect to the logical interpretation of disjunction, allowing them to partition otherwise incosistent input.

Methods

This study used the Providence corpus (Demuth, Culbertson, & Alter, 2006) available via the PhonBank section of the TalkBank archive. The corpus was chosen because of its relatively dense data on child-directed speech as well as the availability of audio and video recordings that would allow annotators access to the context of the utterance. The corpus was collected between 2002 and 2005 in Providence, Rhode Island. Table 2 in appendix reports the name, age range, and the number of recording sessions for the children in this study. All children were monolingual English speakers and were followed between the ages of 1 and 4 years. Based on Study 2, this is the age range when children develop their early understanding of *and* and *or*. The corpus contains 364 hours of biweekly hour-long interactions between parents and children.

Procedure. All utterances containing *and* and *or* were extracted using the CLAN software and automatically tagged for the following: (1) the name of the child; (2) the transcript address; (3) the speaker of the utterance (father, mother, or child); (4) the child's birth date, and (5) the recording date. Since the focus of the study was mainly on disjunction and we did not know how long the annotation of examples would take, we annotated instances of *or* in child-directed speech from the earliest examples to the latest ones. Given that the corpus contained more than 10 times the number of *and*'s than *or*'s, we randomly sampled 1000 examples of *and* to match 1000 examples of *or* in the same age range. After checking for inter-rater reliability, we managed to annotate 608 examples of *or* and 627 examples of *and* the allotted time for annoation.

Annotation Categories. Every extracted instance of *and* and *or* was manually annotated for 8 categories: 1. connective interpretation, 2. logical consistency, 3. utterance type, 4. intonation type, 5. syntactic level, 6. communicative function, and 7. answer type, 8. negation and modals. We briefly explain how each annotation category was defined. Further details and examples are provided in the appendix section.

1. *Connective Interpretation*

This annotation category was the dependent variable of the study. Annotators listened to coordinations such as "A or B" and "A and B", and decided the intended interpretation of the connective with respect to the truth of A and B. We considered the sixteen possible binary connective meanings. Annotators were asked to consider the two propositions raised by the coordinated construction, ignoring the connective and functional elements such as negation. Consider the following sentences containing *or*: "Bob plays soccer or tennis" and "Bob doesn't play soccer or tennis". Both discuss the same two propositions: A. Bob playing soccer, and B. Bob playing tennis. However, the functional elements combining these two propositions result in different interpretations with respect to the truth of A and B. In "Bob plays soccer or tennis" which contains a disjunction, the interpretation is that Bob plays one or possibly both sports (IOR). In "Bob doesn't play soccer or tennis" which contains a negation and a disjunction, the interpretation is that Bob plays neither sport (NOR). For connective interpretations, the annotators first reconstructed the coordinated propositions without the connectives or negation and then decided which propositions were implied to be true/false.

2. *Logical Consistency*

Propositions stand in complex conceptual relations with each other. For example, they can have logical, temporal, or causal relation with each other. For logical consistency, annotators decided whether the propositions that made up the coordination could be true at the same time or not. If the two propositions could not be true at the same time and resulted in a contradiction, they were marked as inconsistent. Our annotators used the following diagnostic to decide the consistency of the disjuncts: Two disjuncts were marked as inconsistent if replacing the word *or* with *and* produced a contradiction. For example, changing "the ball is in my room *or* your room" to "the ball is in my room *and* your room" produces a contradiction because a ball cannot be in two rooms at the same time.

It is important to discuss two issues regarding logical consistency. First, our diagnostic for consistency was quite strict. In many cases, propositions are not inconsistent in this sense but they are rather implausible. For example, drinking both tea and coffee at the same time is consistent, but not likely or plausible. It is possible that many exclusive interpretations are based on such judgments of implausability. Second, if the coordinands are inconsistent, this does not necessarily mean that the connective interpretation must be exclusive. For example, in a sentence like "you could stay here or go out", the alternatives "staying here" and "going out" are inconsistent. Yet, the overall interpretation of the connective could be conjunctive: you could stay here AND you could go out. The statement communicates that both possibilities hold. This pattern of interaction between possibility modals like *can* and disjunction words like *or* are often discussed under "free-choice inferences" in the semantics and pragmatics literature (Kamp, 1973; Von Wright, 1968). Another example is unconditionals such as "Ready or not, here I come!". The coordinands are contradictions: one is the negation of the other. However, the overall interpretation of the sentences is that in both cases, the speaker is going to come.

3. *Utterance Type*

Annotators decided whether an utterance was an instance of a declarative, an interrogative, or an imperative. Occasionally, we found examples with different utterance types for each coordinand. For example, a mother could say "put your backpack on and I'll be right back", where the first coordinand is an imperative and the second a declarative.

Such examples were coded for both utterance types with a dash inbetween: imperative-declarative. Table 5 in the appendix provides the detailed definitions and examples for each utterance type.

4. *Intonation Type*

Annotators listened to the utterances and decided whether the intonation contour on the coordination was flat, rise, or rise-fall. Table 4 in the appendix shows the definitions and examples for these intonation types. In order to judge the intonation of the sentence accurately, annotators were asked to construct all three intonation contours for the same sentence and see which one was closer to the actual intonation of the utterance. For example, to judge the sentence "do you want orange juice↑ or apple juice↓?", they reconstructed the sentence with the prototypical flat, rising, and rise-fall intonations and checked to see which intonation is closer to the actual one.

5. *Syntactic Level*

Annotators marked whether the coordination was at the clausal level or at the sub-clausal level. Clausal level was defined as sentences, clauses, verb phrases, and verbs. Coordination of other categories was coded as sub-clausal. This annotation category was introduced to check the hypothesis that the syntactic category of the coordinands may influence the interpretation of a coordination. For example, a sentence like "He drank tea or coffee" is less likely to be interpreted as exclusive than "He drank tea or he drank coffee." The clausal vs. sub-clausal distinction was inspired by the fact that in many languages, coordinators that connect sentences and verb phrases are different lexical items than those that connect nominal, adjectival, or prepositional phrases (see Haspelmath, 2007).

6. *Communicative Functions*

We constructed a set of categories that captured particular usages or communicative functions of the words *or* and *and*. They include descriptions, directives, preferences, identifications, definitions-examples, clarifications, repairs, and a few others shown in Table 8 in appendix. These communicative functions were created using the first 100 examples and then they were used for the classification of the rest of the examples. Some communicative functions are general and some are specific to coordination. For example, directives are a general class while conditionals (e.g. Put that out of your mouth, or I'm gonna put it away) are more specific to coordinated constructions. It is also important to note that the list is not unstructured. Some communicative functions are subtypes of others. For example, "identifications" and "unconditionals" are subtypes of "descriptions" while "conditionals" are a subtype of directives. Furthermore, "repairs" seem parallel to other categories in that any type of speech can be repaired. We do not fully explore the details of these functions in this study but such details matter for a general theory of acquisition that makes use of the speaker's communicative intentions as early coarse-grained communicative cues for the acquisition of fine-grained meaning such as function words.

7. *Answer Type*

Whenever a parent's utterance was a polar question, the annotators coded the utterance for the type of response it received from the children. This annotation category was different from others because it was not used as a cue for learning disjunction. Instead, it was used as an opportunity to assess (albeit in a limited, indirect, and conservative way) the comprehension of children in the same corpus. Table 9 in the appendix shows the answer types in this study and their definitions and examples. Utterances that were not polar questions were simply coded as NA for this category. If children responded to polar questions with "yes" or "no", the category was YN and if they repeated with one of the coordinands the category was AB. If children said yes/no and followed it with one of the coordinands, the answer type was determined as YN (yes/no). For example, if a child was asked "Do you want orange juice or apple juice?" and the child responded with "yes, apple juice", our annotators coded the response as YN. The reason is that in almost all cases, if a simple yes/no response is felicitous, then it can also be optionally followed with mentioning a disjunct. However, if yes/no is not a felicitous response, then mentioning one of the alternatives is the only appropriate answer. For example, if someone asks "Do you want to stay here or go out?" a response such as "yes, go out" is infelicitous and a better response is simply "go out". Therefore, we counted responses with both yes/no and mentioning an alternative as a yes/no response. We did not annotate for non-verbal answers like headnod or headshake. Therefore, our annotation is a conservative measure that can potentially underestimate children's earlier comprehension of disjunctive questions.

8. *Negation and Modals*

Finally, a script was used to automatically mark utterances for whether they contain sentential negation (*not*/*n't*) or any modal auxiliary such as *maybe*, *can*, *could*, *should*, *would*, or *need to*. This allowed us to see how the presence or absence of negation or modals could affect the overall interpretation of the utterance.

Inter-annotator Reliability. To train annotators and confirm their reliability for disjunction examples, two annotators coded the same 240 instances of disjunction. The inter-annotator reliability was calculated over 8 iterations of 30 examples each. After each iteration, annotators met to discuss disagreements and resolve them. They also decided whether the category definitions or annotation criteria needed to be made more precise. Training was completed after three consecutive iterations showed substantial agreement between the annotators for all categories (Cohen's $\kappa > 0.7$). Further details on inter-annotator reliability are presented in the appendix section.

Exclusion Criteria. We excluded data from Ethan since he was diagnosed with Asperger's Syndrome at age 5. We also excluded all examples found in conversations over the phone, adult-adult conversations, and utterances heard from TV or radio. We did not count such utterances as child-directed speech. We excluded proper names and fixed forms such as “Bread and Circus” (name of a local place) or “trick-or-treat” from the set of examples to be annotated. Such forms could be learned and understood with no actual understanding of the connective meaning. We counted multiple instances of *or* and *and* within the same disjunction/conjunction as one instance. The reasoning was that, in a coordinated structure, the additional occurrences of a connective typically did not alter the annotation categories, and most importantly the interpretation of the coordination. For example, there is almost no difference between “cat, dog, and elephant” versus “cat and dog and elephant” in interpretation. In short, we focused on the “coordinated construction” as a unit rather than on every separate instance of *and* and *or*. Instances of multiple connectives in a coordination were rare in the corpus.

Results

We start with the category "answer type". This category can provide some measure of children’s comprehension by showing when children provide appropriate answers to questions with disjunction. When we look at our dependent variable, namely "connective interpretations". Then we move to the cues that can potentially help the acquisition of connective interpretations.

Answer Types. Figure 5 (Left) shows the monthly proportions of “yes/no” (Y/N) and alternative (AB) answers between the ages of 1 and 3 years. Initially, children provided no answer to questions, but by the age of 3 years, the majority of such questions received a yes/no (YN) or alternative (AB) answer. To assess how often these answers were appropriate, we defined appropriate answers the following way: an alternative (AB) answer is appropriate for an alternative question (one with “or” and a rise-fall intonation). A yes/no answer (YN) is appropriate for a yes/no (polar) question (one with *or* and a rising intonation). Of course this classification is strict and misses some nuanced cases, but

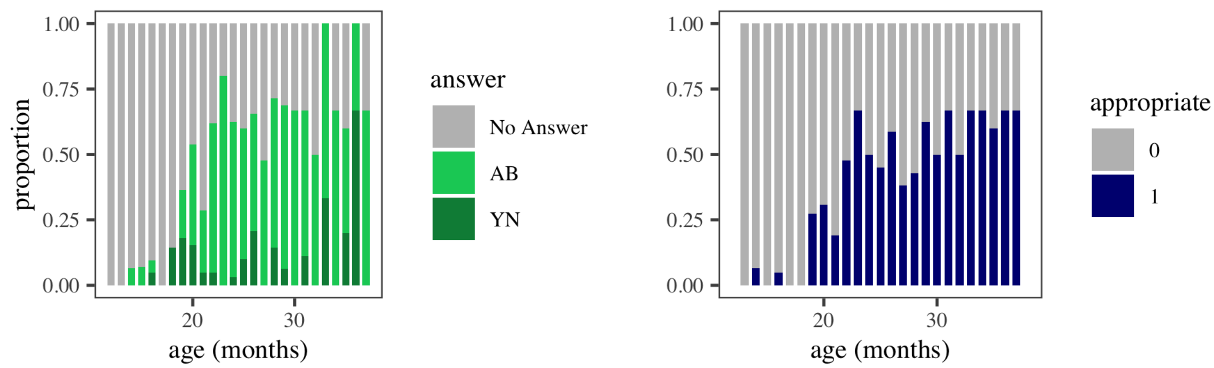

Figure 5. Left: Monthly proportions of children's yes/no (YN) and alternative (AB) answers to questions with *or*. Right: Monthly proportions of children's appropriate answers to questions with *or*.

nevertheless provides a useful conservative estimate. The right side of Figure 5 shows the monthly proportion of children's appropriate answers between the ages of 1 and 3. The results show that even with a conservative measure, children show an increase in the proportion of their appropriate answers to questions containing *or* between 20 to 30 months of age (roughly 2 and 3 years of age). This in turn suggests that initial form-meaning mappings for disjunction is formed in this age range. The rest of this section discusses the cues that can assist children create successful form-meaning mappings.

Connective Interpretation. Figure 6 (Left) shows the overall distribution of the connective interpretations in child-directed speech regardless of the connective word. The most common interpretation was conjunction (AND, 55%) followed by exclusive disjunction (XOR, 31%). Figure 6 (Right) shows the distribution of connective interpretations broken down by the connective word used: *and* vs. *or*[1]. Almost all instances of the connective *and*, were interpreted as conjunction (AND). There were also a small number of NAND interpretations (e.g. "don't swing that in the house and hit things with it") and IFF interpretations (e.g. "come here and I'll show you") in our sample. For the connective *or*,

[1]All the confidence intervals shown in the plots for this section are simultaneous multinomial confidence intervals computed using the Sison and Glaz (1995) method.

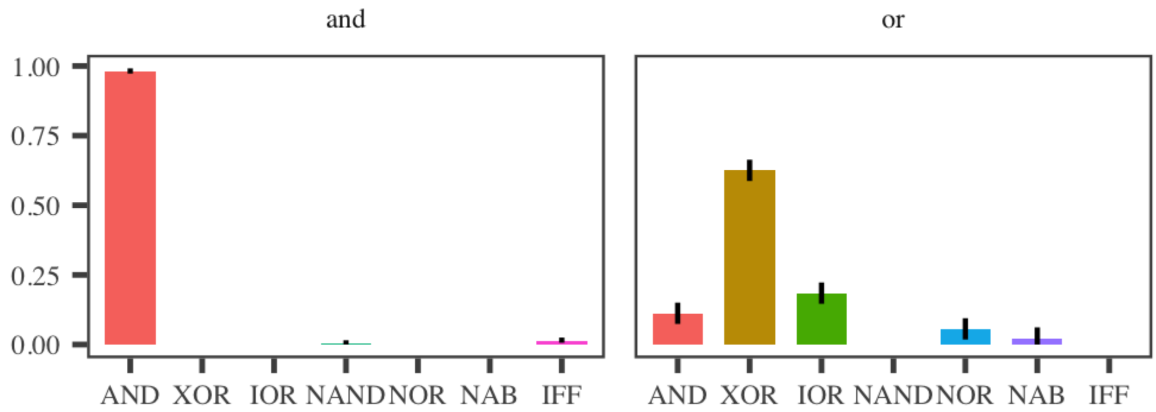

Figure 6. Left: Connective interpretations in child-directed speech. Right: Connective interpretations broken down by lexical items *and* (conjunction) and *or* (disjunction).

the most frequent interpretation was exclusive disjunction (XOR, 62%) followed by inclusive disjunction (IOR, 18%) and conjunction (AND, 11%). There were also a small number of NOR (e.g. "you never say goodbye or thank you") and NAB interpretations (e.g. "those screws, or rather, those nuts"). Overall, these results are consistent with the findings of Morris (2008) who concluded that exclusive disjunction is the most common interpretation of *or*. Therefore, by simply associating the most common interpretations with the connective words, a learner is expected to learn *and* as conjunction, and *or* as exclusive disjunction (Crain, 2012; Morris, 2008). However, the learning outcome might be different if factors other than the connective word are also considered. In the next section, we investigate how different annotation categories introduced earlier correlate with the interpretations of *or*.

Cues to Disjunction Interpretation. We set *and* aside because it was almost always interpreted as conjunction (AND). Figure 7 shows the proportions of connective interpretations in disjunctions with consistent vs. inconsistent disjuncts. When the disjuncts were consistent (i.e. could be true at the same time), the interpretation could be exclusive (XOR), inclusive (IOR), or conjunctive (AND). When the disjuncts were inconsistent, a

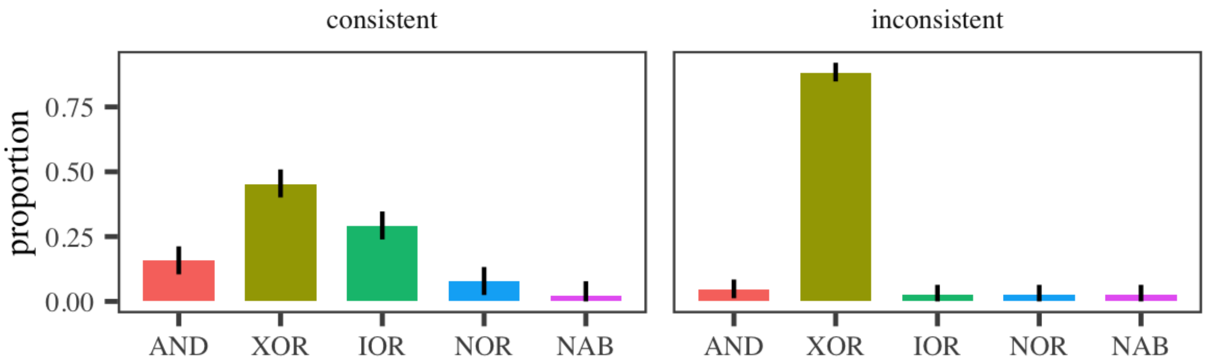

Figure 7. Interpretations of disjunction in child-directed speech with consistent vs. inconsistent disjuncts.

disjunction almost always received an exclusive (XOR) interpretation. This suggests that the exclusive interpretation of a disjunction often stems from the inconsistent or contradictory nature of the disjuncts themselves[2].

Next we focus on cases of disjunction with consistent disjuncts. Figure 8 shows their interpretations in declarative, interrogative, and imperative sentences. Interrogatives selected for exclusive and inclusive interpretations. Imperatives were more likely to be interpreted as inclusive (IOR), but declaratives could receive almost any interpretation: conjunctive (AND), exclusive (XOR), inclusive (IOR), or even that "neither" disjunct was true (NOR). A common example of inclusive imperatives was invitation to action such as "Have some food or drink!". Such invitational imperatives seem to convey inclusivity (IOR) systematically. They are often used to give the addressee full permission with respect to both alternatives. It can in fact be odd to use them to imply exclusivity (e.g. "Have some food or drink, but

[2]It should be noted here that in all *and*-examples, the disjuncts were consistent. This is not surprising given that inconsistent meanings with *and* result in a contradiction. The only exception to this was one example where the mother was mentioning two words as antonyms: "short and tall". This example is quite different from the normal utterances given that it is meta-linguistic and list words rather than asserting the content of the words.

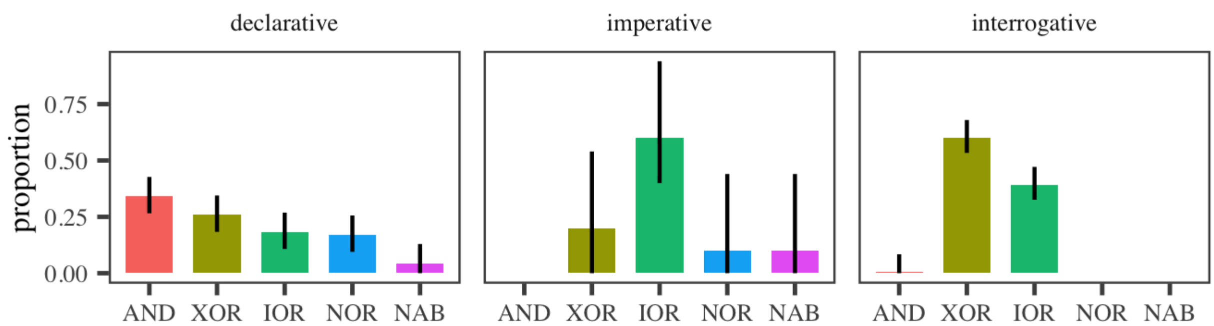

Figure 8. Interpretations of disjunction with consistent disjuncts in interrogative, imperative, and declarative utterances.

not both!"), and they are not conjunctive either, i.e inviting the addressee to do both actions (e.g. "Have some food, and have some drink!").

While interrogatives selected for exclusive and inclusive interpretations, their intonation could distinguish between these two readings. Figure 9 shows the interpretations of consistent disjunction in three intonational contours: flat, rise, and rise-fall. The rise and rise-fall contours are typical of interrogatives. The results show that, a disjunction with a rise-fall intonation is most likely interpreted as exclusive (XOR). If the intonation is rising, a disjunction is most likely inclusive (IOR). Finally, a disjunction with a flat intonation (typical of declaratives and imperatives) could be interpreted as exclusive (XOR), conjunctive (AND), inclusive (IOR), or neither (NOR). These results replicate Pruitt and Roelofsen (2013)'s experimental findings on the role of intonation in the interpretation of polar and alternative questions.

Next we focus on consistent disjunctions with flat intonation. Figure 10 breaks down the interpretations based on whether the utterance contained negation or modals. The results show that in the presence of a modal such as *can* or *maybe*, it was more likely for a disjunction to have a conjunctive interpretation. This is consistent with the literature on

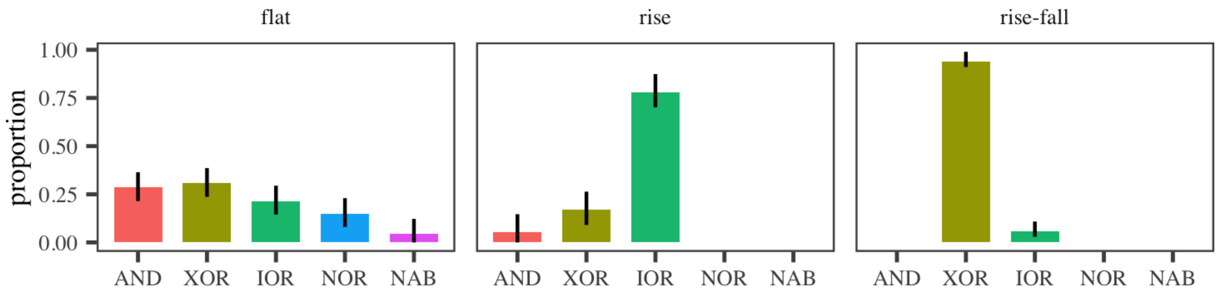

Figure 9. Interpretations of disjunction with consistent disjuncts and flat, rising, or rise-fall intonation.

free-choice inferences in formal semantics and pragmatics (Kamp, 1973), which shows statements such as “you can have tea or coffee” is interpreted conjunctively as “you can have tea *and* you can have coffee”. When the utterance contained a negation, the disjunction could be interpreted as exclusive (XOR) or neither (NOR). These two interpretations correspond to the scope relations between negation and disjunction. If negation scopes above disjunction, we get a neither (NOR) interpretation (e.g. “I do not eat cauliflower, cabbage or baked beans.”) But if disjunction scopes above negation, the likely interpretation is exclusive (e.g. don’t throw it at the camera or you’re going in the house.) These results also suggest that a learner who tracks co-occurences of *or* with negative morphemes can potentially learn about the scope interaction of disjunction and negative particles in their native language.

Finally, we visit the last two remaining categories: syntactic level and communicative functions. For these categories, we show connective interpretations over all instances of disjunction. Figure 11 shows connective interpretations, broken down by syntactic level. The results suggest a possible small effect of clausal level disjuncts. Disjunctions were more likely to be interpreted as exclusive if their disjuncts were clauses or verbs rather than nominals, adjectives, or prepositions (all sub-clausal units). As explained before, the intuition is that a sentences such as “They had tea or coffee” is less likely to be exclusive than “they had tea or

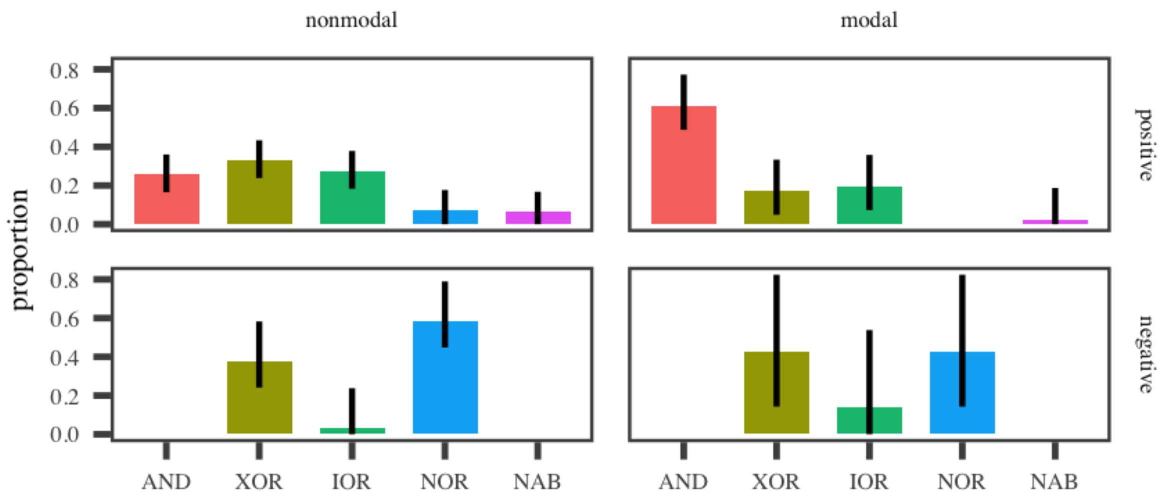

Figure 10. Distribution of connective interpretations for consistent disjuncts with flat intonation.

they had coffee." However, our understanding is that compared to other factors such as intonation and consistency, the effect of syntactic level was very small. As we shall see in Study 3, a computational learning model did not find syntactic level to be of much use for classifying instances of disjunction as exclusive, above and beyond what other annotation categories offered.

Figure 12 shows connective interpretations in the 10 different communicative functions we defined. The results show that certain functions increase the likelihood of some connective interpretations. An exclusive interpretation (XOR) is common in acts of clarification, identification, stating/asking preferences, stating/asking about a description, or making a conditional statements. These results are consistent with expectations on the communicative intentions that these utterances carry. In clarifications, the speaker needs to know which of two alternatives the other party meant. Similarly in identifications, speaker needs to know which category does a referent belongs to. In preferences, parents seek to know which of two alternatives the child wants. Even though descriptions could be either inclusive or exclusive,

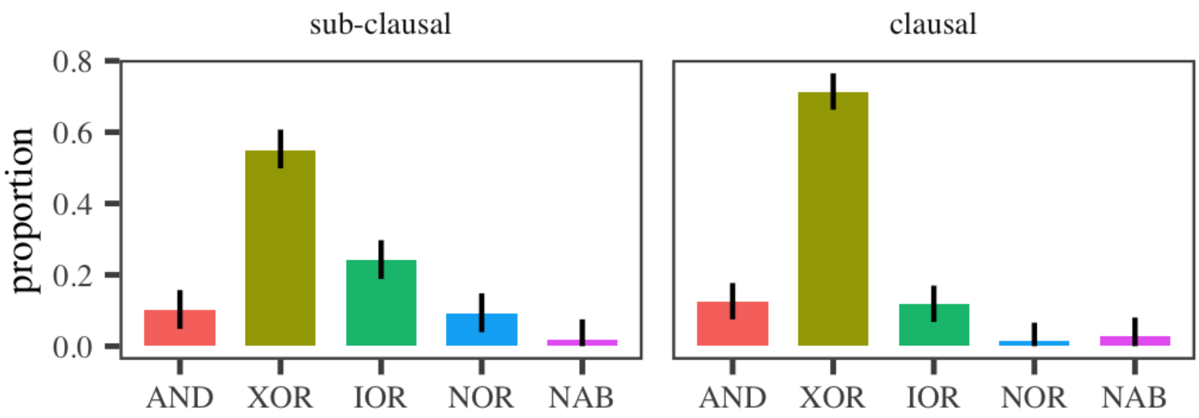

Figure 11. Top: Interpretations of clausal vs. sub-clausal disjunction. Down: Interpretations of clausal vs. sub-clausal disjunction in declaratives with consistent disjuncts.

in the current sample, most descriptions were questions about the state of affairs and required the child to provide one of the alternatives as the answer. In conditionals such as "come here or you are grounded", the point of the threat is that only one disjunct can be true: either "you come and you are not grounded" or "you don't come and you are grounded".

Repairs often received an exclusive (XOR) or a second-disjunct-true (NAB) interpretation. This is expected given that in repairs the speaker intends to say that the first disjunct is incorrect or inaccurate. Unconditionals and definitions/examples always had a conjunctive (AND) interpretation. Again, this is to be expected. In such cases the speaker intends to communicate that all options apply. If the mother says that "cats are animals like lions or tigers", she intends to say that both lions and tigers are cats, and not one or the other. Interestingly, in some cases, *or* is replaceable by *and*: "cats are animals like lions and tigers". In unconditionals, the speaker communicates that in both alternatives, a certain proposition holds. For example, if the mother says "ready or not, here I come!", she communicates that "I come" is true in both cases where "you are ready" and "you are not ready".

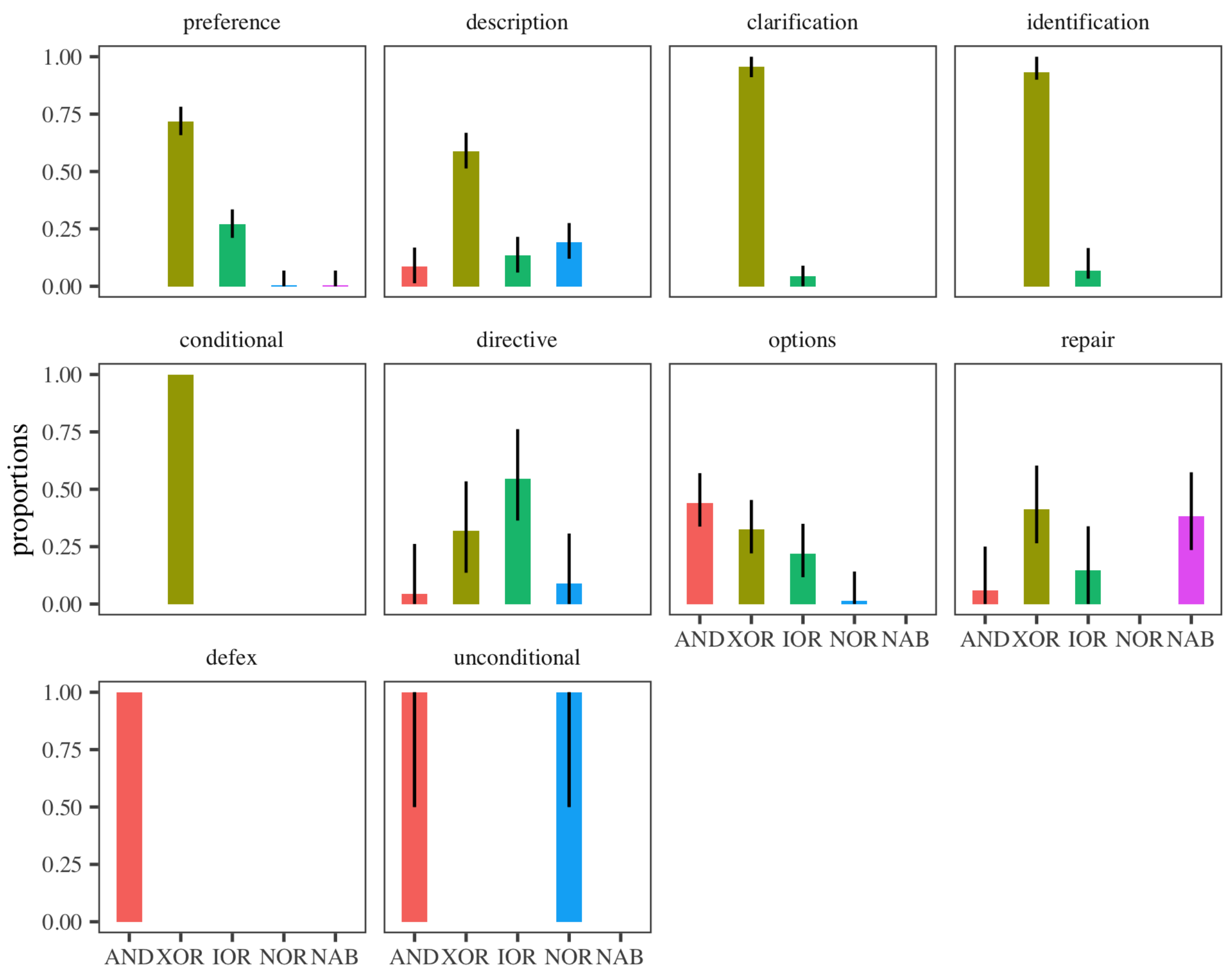

Figure 12. Interpretations of disjunction in different communicative functions.

Options were often interpreted either as conjunctive (AND) or inclusive (IOR). The category "options" contained examples of free-choice inferences such as "you could drink orange juice or apple juice". This study found free-choice examples to be more common in child-directed speech than the current literature on the acquisition of disjunction assumes. Finally, directives received either an IOR or XOR interpretation. It is important to note here that the most common communicative function in the data were preferences and descriptions. Other communicative functions such as unconditionals or options were fairly rare. Despite their infrequent appearance, these constructions must be learned by children at some point, since almost all adults know how to interpret them.

Conclusion

This study focused on the interpretations that connectives *and* and *or* recieve in child-directed speech. It also investigated some candidate cues that can help children's learning of these interpretations. The study annotated examples of *and* and *or* in child-directed speech for their truth-conditional interpretation, as well as 6 candidate cues: logical consistency, utterance type, intonation, presence of negative or modal morphemes, syntactic level of the coordinands, and communicative function of the coordination. Like Morris (2008), this study found that the most common interpretations of *and* and *or* are conjunction (AND) and exclusive disjunction (XOR) respectively. Therefore, relying only on connective word forms, we should expect a learner to learn *and* as conjunction and *or* as exclusive disjunction.

However, the study also found that the most likely interpretation of a disjunction depended on the cues that accompanied it in context. A disjunction was most likely exclusive if the alternatives were inconsistent (i.e. contradictory). If the alternatives were consistent, then the disjunction was either inclusive or exclusive if it appeared in a question. Within questions, if the intonation on the disjunction was "rising", it was inclusive, and if the intonation was "rise-fall" then it was mostly likely exclusive. Among declaratives and imperatives with "flat" intonations, a disjunction was interpreated most liklely as AND if there was a modal, and NOR or XOR if there was negation present in the utterance. Finallly, in the absence of all these cues, a disjunction was more likely to be non-exclusive (IOR + AND) than exclusive (XOR). These results suggest that numerous cues have some informational value about the interpretation of disjunction and a learner can potentially use them to predict the intended interpretation in context. In the next study, we use a computational learning model to formalize this account and systematically select cues that have the highest informational value for the interpretation of disjunction.

Computational Model

In this study, we use decision tree learning to test the reliability of the cues to disjunction interpretation in child-directed speech and assess which cues have more informational value. A decision tree is a classification model structured as a hierarchical tree with an initial node, called the root, that branches into more nodes until it reaches the leaves (Breiman, 2017). Each node represents a test on a feature, each branch represents an outcome of the test, and each leaf represents a classification label. Using a decision tree, observations can be classified or labeled based on a set of features. Decision trees have at least four advantages for modeling cue-based accounts of semantic acquisition. First, the features used in decision trees for classification can stand for the cues that help the acquisition and interpretation of a word or an utterance. Second, it is possible to make decision trees more or less reliant on the available cues in the data. This way we can explore the success of models with more or less cue-dependence. Third, unlike many other machine learning techniques, decision trees result in models that are interpretable. Fourth, the order of decisions or features used for classification is determined based on information gain. Features that appear higher (earlier) in the tree are more informative and helpful for classification. Therefore, decision trees can help us understand which cues are more helpful for the acquisition and interpretation of words.

Decision tree learning is the construction of a decision tree from labeled training data. This study applies decision tree learning to the annotated data of Study 2 by constructing random forests (Breiman, 2001; Ho, 1995). In random forest classification, multiple decision trees are constructed on subsets of the data, and each tree predicts a classification. The ultimate outcome is a majority vote of each tree's classification. Since decision trees tend to overfit data, random forests control for overfitting by building more trees and averaging their results (Breiman, 2001; Ho, 1995). The next section discusses the methods used in constructing the random forests for interpreting the connectives *or* and *and*.

Methods

The random forest models were constructed using python's Sci-kit Learn package (Pedregosa et al., 2011). The annotated data had a feature array and a connective interpretation label for each connective use. Connective interpretations included exclusive (XOR), inclusive (IOR), conjunctive (AND), neither (NOR), and NPQ which states that only the second proposition is true. The features or cues used included the following annotation categories: intonation, consistency, utterance type, syntactic level, negation, and communicative function. All models were trained with stratified 10-Fold cross-validation to reduce overfitting. Stratified cross-validation maintains the distribution of the initial data in the random sampling to build cross validated models. Maintaining the data distribution ensures a more realistic learning environment for the forests. Tree success was measured with F1-Score, harmonic average of precision and recall (Rijsbergen, 1979).

First a grid search was run on the hyperparamter space to establish the number of trees in each forest and the maximum tree depth allowable. The grid search creates a grid of all combinations of forest size and tree depth and then trains each forest from this grid on the data. The forests with the best F1-score and lowest size/depth are reported (Pedregosa et al., 2011). The default number of trees for the forests was set to 20, with a max depth of eight and a minimum impurity decrease of 0. Impurity was measured with gini impurity, which states the odds that a random member of the subset would be mislabled if it were randomly labeled according to the distribution of labels in the subset. (Gini, 1912).

Decision trees were fit with high and low minimum-gini-decrease values. High minimum-gini-decrease results in a tree that does not use any features for branching. Such a tree represents the baseline or traditional approach to mapping that directly maps a word to its most likely interpretation. Low minimum-gini-decrease allows for a less conservative tree that uses multiple cues or features to predict the interpretation of a disjunction. Such a tree represents the cue-based context-sensitive account of word learning.

Results

We first present the results of the random forests in a binary classification task. The models were trained to classify exclusivity, i.e. whether an interpretation was exclusive or not. In the section after, we use a more general classifier to predict all interpretations of disjunction using the annotated cues. For visualization of trees, we selected the highest performing tree in the forest by testing each tree and selecting for highest F1 score. While the forests performance is not identical to the highest performing tree, the best tree gives an illustrative example of successful learning from data.

Detecting Exclusivity. Figure 13A shows the best performing decision tree with high minimum gini decrease. As expected, a learner that does not use any cues would interpret *or* as exclusive all the time. This is the baseline model. Figure 13B shows the best performing decision tree with low minimum gini decrease. The tree has learned to use intonation and consistency to classify disjunctions as exclusive or inclusive. As expected, if the intonation is rise-fall or the disjuncts are inconsistent, the interpretation is exclusive. Otherwise, the disjunction is classified as not exclusive.

Figure 13C shows the average F1 scores of the baseline and cue-based models in classifying exclusive examples as the number of training examples increases. The models perform similarly, but the cue-based model performs slightly better. The real difference between the baseline model and the cue-based model is in their performance on inclusive examples. Figure 13D shows the F1 score of the forests as a function of the training size in classifying inclusive examples. As expected, the baseline model performs very poorly while the cue-based model improves with more examples and performs better than the baseline tree.

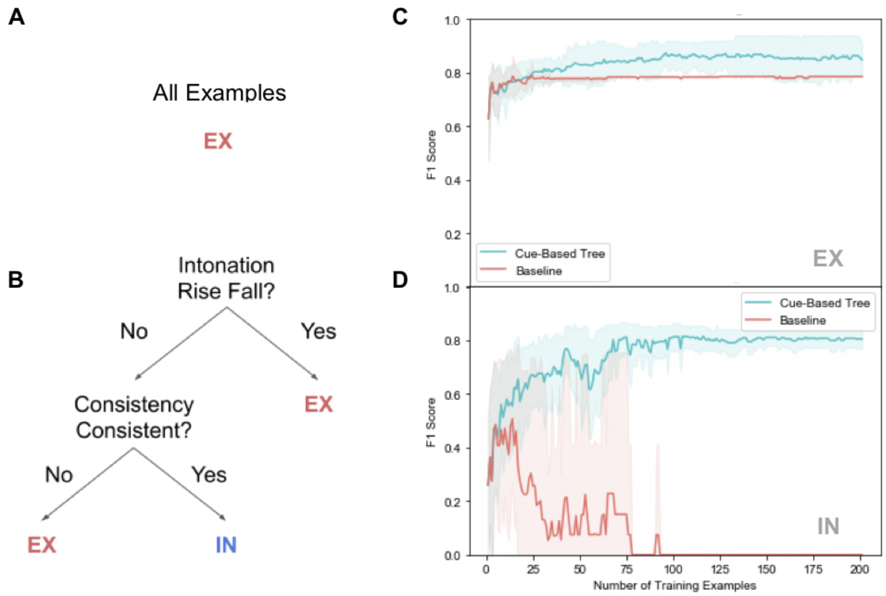

Figure 13. (A) The structure for the baseline (highest gini threshold, 0.2) decision tree trained on examples with exclusive (EX) and non-exclusive (IN) interpretations. (B) The structure for the cue-based decision tree (low gini threshold of 0.01). The average F1 score with 95% confidence intervals as a function of the number of training examples in the baseline and cue-based model when treating as positive (C) EX and (D) IN respectively.

Detecting All Interpretations. We next look at decision trees trained on the annotation data to predict all the interpretation classes for disjunction: AND, XOR, IOR, NOR, and NPQ. Figure 14A shows the baseline model that only uses the words *and* and *or* to classify. As expected, *and* receives a conjunctive interpretation (AND) and *or* receives an exclusive interpretation (XOR). Figure 14B shows the best example tree of the cue-based model. The leaves of the tree show that it recognizes exclusive, inclusive, conjunctive, and even neither (NOR) interpretations of disjunction. How does the tree achieve that? Like the baseline model, the tree first asks about the connective used: *and* vs. *or*. Then like the previous cue-based model, it asks about intonation and consistency. If the intonation is rise-fall, or the disjuncts are inconsistent, the interpretation is exclusive. Then it asks whether the sentence is an interrogative or a declarative. If interrogative, it guesses an inclusive interpretation. This basically covers questions with a rising intonation. Then the tree picks declarative examples that have conditional speech act (e.g. "give me the toy or you're grounded") and labels them as exclusive. Finally, if negation is present in the sentence, the tree labels the disjunction as NOR.

Figures 14C, 14D, and 14E show the average F1-scores for the conjunctive (AND), exclusive (XOR), and inclusive (IOR) interpretations as a function of training size. While the cue-based model generally performs better than the baseline model, it shows substantial improvement in classifying inclusive cases. Figure 14F shows the average F1-score for the neither interpretation as a function of training size. Compared to the baseline model, the cue-based model shows a substantially better performance in classifying negative sentences. The success of the model in classifying neither examples (NOR) suggests that the cue-based model offers a promising approach for capturing the scope relation of operators such as negation and disjunction. Here, the model learns that when negation and disjunction are present, the sentence receives a neither (NOR) interpretation. In other words, the model has learned the narrow-scope interpretation of negation and disjunction from the input data. In a language where negation and disjunction receive an XOR interpretation (not A or not B), the cue-based model can learn the wide-scope interpretation of disjunction.

Finally, Figure 14G shows the average F1 score for the class NPQ. This disjunct interpretation suggested that the first disjunct is false but the second true. NPQ was by-far the most infrequent of the considered disjuncts (n=6), was not in every tree in the random forests, and was not present in the highest performing tree. However, considering the data, it was seen in examples of repair most often and the most likely cue to it was also the communicative function or speech act of repair. The results show that even though there were improvements in the cue-based model, they were not stable as shown by the large confidence intervals. It is possible that with larger training samples, the cue-based model can reliably classify the NPQ interpretations as well.

Conclusion

In this study, we used the annotation data from Study 2 to train and compare two random forest models, representing two accounts for the acquisition of disjunction. The first account was a baseline (context-independent) account in which words are isolated and directly mapped to their most likely meanings, disregarding available contextual cues. Random forest models with high minimum-gini-impurity-decrease represented this account. The second account was what we called the cue-based context-dependent mapping in which words are mapped to meanings using a set of cues available in the context. Random forest models with low minimum-gini-impurity-decrease represented this cue-based account. Comparison of the F1-Scores produced by models representing these two accounts showed that the cue-based models outperfromed the baseline models in every classification task. Most importantly, while the baseline models learned to always interpret a disjunction as exclusive, the cue-based models learned to interpret a disjunction as exclusive, inclusive, conjunctive, or neither (NOR), depending on the cues available in the input.

General Discussion

This paper presented three studies to support the claim that child-directed speech contains linguistic cues for successful interpretation of linguistic disjunction and that mapping *or* to its meaning in a cue-based context-dependent manner would address the puzzle of learning disjunction. Study 1 presented the overall distribution of *or* and *and* in parents' and children's speech in CHILDES corpora. It showed that children heard 1-2 examples of *or* in every thousand words parents produced. Children started producing *or* themselves between 18-30 months, and by 42 months they reached a rate of one *or* per thousand words. Study 2 showed that as Morris (2008) had found, the most common interpretation of *or* in child-directed speech was exclusive disjunction. However, exclusive interpretations were accompanied by prosodic and semantic cues. In the absence of these cues to exclusivity, the interpretation of a disjunction was most likely non-exclusive. Finally, study 3 used decision-tree learning to show that an ideal learner can use these linguistic cues to partition the input and predict the interpretation of a linguistic disjunction.

Here we address some important limitations of the present account that future work should address. The computational model in study 3 represents an ideal observer (Geisler, 2003). It helps us measure the information available in the input for mapping *or*, provides a computational theory of how to perform this task, and serves as a starting point for developing more realistic models. Future research should improve on at least three important aspects of this model. First, the model had access to a limited set of pre-selected cues for learning. Similar to other cue-based accounts (Monaghan & Christiansen, 2014), this account needs to explain how the learner can discover and select the relevant cues for the acquisition of disjunction among potentially many possible candidate cues. Fortunately the cues that are relevant to acquisition of *or* are not idiosyncratic. Intonation and the semantics of the neighboring words are cues that always need to be monitored for the interpretation of almost any word. Therefore, it is possible that there are a limited number of salient factors or cues in child-directed speech that guide form-meaning mapping and future research can uncover them.

Second, our account and consequently model assumed the 16 binary logical connective concepts for mapping *or*. Future work on our account, as well as other accounts of learning disjunction, needs to explain how children limit their conceptual space to connective concepts when mapping words like *and* and *or*. We believe that a promising approach to addressing this problem is syntactic bootstrapping (Brown, 1957; Gleitman, 1990). Previous research has shown that syntactic bootstrapping can help learners filter their conceptual space appropriately for many word classes such as nouns (Soja, 1992), verbs (Naigles, 1990), adjectives (Taylor & Gelman, 1988), and prepositions (Landau & Stecker, 1990). It is probable that the same mechanism applies to connectives, especially that as pointed out by

Haspelmath (2007), coordination has specific syntactic properties. Coordinators combine two or more units of the same type and return a larger unit of the same type. The larger unit has the same semantic relation with the surrounding words as the smaller units would have had without coordination. These properties separate coordinators from other function words, which are not used to connect sentences or any two similar units for that matter. Third, our ideal observer model was implemented using a supervised learning algorithm and had access to labeled training data. While it is not clear what form of feedback children receive while learning function words like *or*, it is clear that they do not have access to the kind of labeled data the decision trees had. Future work should revise this aspect of the model and incorporate feedback that is realistic with respect to children's language acquisition (Chouinard & Clark, 2003; Clark, 2010).

Furthermore, our study has shown the potential utility of cues for the acquisition of disjunction, but it is important for future experimental research to follow up and show that children are sensitive to these cues and in fact use them to learn the meaning of disjunction words like *or*. For example, there is already some research suggesting that infants are sensitive to intonational cues. Frota, Butler, and Vigário (2014) have shown that 5-9 month-olds discriminate rising yes/no intonation typical to questions from the falling intonation typical to statements. More importantly, Esteve-Gibert, Prieto, and Liszkowski (2017) have shown that 12 month-olds can use gesture and intonation to distinguish basic speech acts like commands and statements from each other. These findings suggest that by the time children start their early mappings for disjunction, perhaps around 18 months of age, they may already be sensitive to the role of intonation in conveying linguistic meaning. In the future, we would like to test toddler's sensitivity to the intonation of disjunctive statements as well as other cues such as the logical consistency of coordinands connected by *and* and *or*.

Finally, we would like to place our findings in the bigger context of word learning. As discussed in the introduction, Quine (1960) mentioned three general strategies for learning the lexicon of a language. He hypothesized that for many content words, especially concrete nominals, adjectives, or verbs, language learners initially map their meanings using the isolated strategy. They rely on salient aspects of their physical experience as well as biases, cues, and mechanisms that aid isolated mapping. For example, they may associate *ball* as the label for round objects they play with, or *sit* as the action they perform before having food or wearing shoes. In other words, children start word learning by creating word-to-world mappings. Then they can rely on the growing number of such mappings to figure out the meaning of novel words that appear in the same linguistic context as these known words. For example, hearing constructions like "sit and eat" or "clean and shiny" may allow children to infer that the connective *and* is used when the speaker intends both coordinands. Connective *or*, on the other hand, appears commonly in constructions like "sit or stand" and "clean or dirty" where the coordinands are inconsistent and only one or the other can apply in typical everyday contexts. Therefore, the early isolated mappings help constrain the hypotheses for what unknown function words can mean, given that they should create the overall message of the utterance in combination with known words. Once enough function and content words are learned using isolated and context-dependent mappings, the learner can use the extreme case of learning from the linguistic context, namely mapping the meaning of a word to a linguistic definition. For example, a child may learn from their parents that *below* is "another word for under" or that *carving* is "cutting wood" (Clark, 2010).

More recently, Gleitman et al. (2005) proposed a similar developmental account but emphasized the role of syntax and compositional structure in learning from the linguistic context. They argued that children start with "easy words", mostly nominals that express concrete basic-level concepts, which require word-to-world mappings. Once children have a stock of easy words, they can use it along with their syntactic knowledge to create "structure-to-world mappings" and learn the meaning of "hard words" like mental verbs (e.g. *think* and *know*). Several "syntactic cues" such as the number of the verb's arguments, the argument position (subject vs. object), as well as argument type (the type of meanings the arguments have) constrain the hypothesis space for verb meaning. They called this account "syntactic bootstrapping" and suggested that a general probabilistic learning mechanism combines and coordinates multiple cues to map words to their intended meanings. Our account of English disjunction is in line with Quine (1960) and Gleitman et al. (2005), contributing to this literature in at least four ways. First, our work highlights the role of prosody in form-meaning mapping. Prosody is considered an important source of information for learning a language's structure (Carvalho, He, Lidz, & Christophe, 2019) and our work suggests that it can also play an important role in addressing the form-meaning mapping problem. Second, it emphasizes the role of semantic relation among words in an utterance as another cue to form-meaning mapping. Gleitman et al. (2005) discuss this to some extent under "distributional cues", which refer to the meaning of other words co-occurring with the unknown words. However, our work on disjunction adds that the entailment relation between the disjuncts, and more specifically whether or not they lead to logical inconsistency, can help a learner map the meaning of a disjunction word like *or*. Third, our work suggests that cues may play a more complex role than previously assumed. Previous literature has shown that cues can boost a particular hypothesis against others or bias the learner to reduce uncertainty. Our work suggests that cues may also be able to affect the mapping mechanism itself: the way words are mapped to hypothesized meanings. With respect to disjunction, they may be able to break down the input into their "context of use" and allow the learner to map words to their meanings in a context-dependent manner. Fourth, in our work we make some initial steps in quantifying and formalizing the probabilistic cue-integration account of form-meaning mapping using decision-tree learning.

Research on the role of linguistic context in word learning has a long history. Werner and Kaplan (1952) devised an experimental task in which a nonsense word like *cantavish* was used in 6 different sentences like "a bottle has only one cantavish" and "John fell into a cantavish in the road". Children (age 8 to 13 years) were asked to guess the meaning of the nonsense word. They reported that children can successfully guess the meaning of nonsesnse words and they guessed more correctly as they grew older but part of the difficulty in young children stemmed from adapting to the nature of the task itself. Sternberg and Powell (1983) focused on reading comprehension and placed contextual word learning within a bigger theory of verbal comprehension, classifying contextual cues as external or internal. External cues were those provided by known words surrounding the unknown word and internal cues those internal to the word such as known prefixes, stems, or suffixes. For each class of cues, they proposed mediating factors that affected word learning such as the frequency of the unknown word, its concreteness, the density of all unknown words, and context variability (how variable were the co-occurring words around the unknown word). Beals (1997) focused on naturalistic child-parent interactions during mealtime and found that most “rare words” (words children are not expected to know) such as *cramps* or *license* are often uttered with considerable semantic support: the linguistic context could provide some initial meaning for them. In some of these cases the semantic support came in the shape of explicit definitions. For example, when the mother used the word *cramps* and the child asked what they are, the mother responded with “cramps are when your stomach feels all tight and it hurts cause you have food in it.” Clark (2010) provides many examples of contextual support and overt explanations or definitions for nouns, verbs, adjectives, and spatial prepositions.

When it comes to function words, as Quine pointed out, the linguistic context is most likely a major source of information. Therefore, discovering biases, cues, or mechanisms that help the acquisition of function words is an important step in developing a general theory of word learning. This paper provided some initial steps in this direction. An important future step is discovering and quantifying the extent to which different types of linguistic cues contribute to different word classes. However, as Quine explained, which strategy is applied at each stage of the development may also vary considerably by individual learners. For example, the word *iPhone* may be learned using the isolated strategy for some children who experience it early in some families or cultures while for others it may be primarily learned contextually. Nevertheless, learning from the linguistic context is expected to play a major role in the acquisition of the lexicon in all languages (Sternberg, 1987). Function words are an important part of this overall picture of word learning and future research should focus on discovering biases, cues, and mechanisms that result in their successful acquisition.

References

Appendix

Table 2

Information on the participants in the Providence Corpus. Ethan was diagnosed with Asperger's syndrome and therefore was excluded from this study.

Name	Age Range	Sessions
Alex	1;04.28-3;05.16	51
Ethan	0;11.04-2;11.01	50
Lily	1;01.02-4;00.02	80
Naima	0;11.27-3;10.10	88
Violet	1;02.00-3;11.24	51
William	1;04.12-3;04.18	44

Annotation Categories

Table 3

Annotation classes for connective interpretation

Class	Meaning	Examples
AND	Both propositions are true	*"I'm just gonna empty this and then I'll be out of the kitchen." – "I'll mix them together or I could mix it with carrot, too."*
IOR	One or both propositions are true	*"You should use a spoon or a fork." – "Ask a grownup for some juice or water or soy milk."*
XOR	Only one proposition is true	*"Is that a hyena? or a leopard?" – "We're gonna do things one way or the other."*

Class	Meaning	Examples
NOR	Neither proposition is true	*“I wouldn’t say boo to one goose or three.” – “She found she lacked talent for hiding in trees, for chirping like crickets, or humming like bees.”*
IFF	Either both propositions are true or both are false	*“Put them [crayons] up here and you can get down. – Come over here and I’ll show you.”*
NAB	The first proposition is false, the second is true.	*“There’s an Oatio here, or actually, there’s a wheat here.”*

Table 4

Definitions of the intonation types and their examples.

Intonation	Definitions	Examples
Flat	Intonation does not show any substantial rise at the end of the sentence.	*“I don’t hear any meows or bow-wow-wows.”*
Rise	There is a substantial intonation rise on each disjunct or generally on both.	*“Do you want some seaweed? or some wheat germ?”*
Rise-Fall	There is a substantial rise on the non-final disjunct(s), and a fall on the final disjunct.	*“Is that big Q or little q?” – “(are) You patting them, petting them, or slapping them?”*

Table 5

Definitions of the utterance types and their examples.

Utterance Types	Definitions	Examples
Declarative	A statement with a subject-verb-object word order and a flat intonation.	*"It looks a little bit like a drum stick or a mallet."*
Interrogative	A question with either subject-auxiliary inversion or a rising terminal intonation.	*"Is that a dog or a cat?"*
Imperative	A directive with an uninflected verb and no subject	*"Have a little more French toast or have some of your juice."*

Table 6

Definitions of the syntactic levels and their examples.

Syntactic Level	Definitions	Examples
Clausal	The coordinands are sentences, clauses, verb phrases, or verbs.	*"Does he lose his tail sometimes and Pooh helps him and puts it back on?"*
Sub-clausal	The coordinands are nouns, adjectives, noun phrases, determiner phrases, or prepositional phrases.	*"Hollies can be bushes or trees."*

Table 7

Definitions of consistency types and their examples.

Consistency	Definitions	Examples
Consistent	The coordinands can be true at the same time.	*"We could spell some things with a pen or draw some pictures."*
Inconsistent	The coordinands cannot be true at the same time.	*"Do you want to stay or go?"*

Table 8

Definitions of the communicative functions and their examples.

Function	Definitions	Examples
Descriptions	Describing what the world is like or asking about it. The primary goal is to inform the addressee about how things are.	"*It's not in the ditch or the drain pipe.*"
Identifications	Identifying the category membership or an attribute of an object. Speaker has uncertainty. A subtype of "Description".	"*Is that a ball or a balloon honey?*"
Definitions and Examples	Providing labels for a category or examples for it. Speaker is certain. Subtype of Description.	*"This is a cup or a mug." – "berries like blueberry or raspberry"*
Preferences	Asking what the addressee wants or would like or stating what the speaker wants or would like	*"Do you wanna play pizza or read the book?"*

Function	Definitions	Examples
Options	Either asking or listing what one can or is allowed to do. Giving permission, asking for permission, or describing the possibilities. Often the modal "can" is either present or can be inserted.	*"You could have wheat or rice."*
Directives	Directing the addressee to act or not act in a particular way. Common patterns include "let's do . . . ", "Why don't you do . . . ", or prohibitions such as "Don't . . . ". The difference with "options" is that the speaker expects the directive to be carried out by the addressee. There is no such expectation for "options".	*"let's go back and play with your ball or we'll read your book."*
Clarifications	Something is said or done as a communicative act but the speaker has uncertainty with respect to the form or the content.	*"You mean boba or bubble?"*
Repairs	Speaker correcting herself on something she said (self repair) or correcting the addressee (other repair). The second disjunct is what holds and is intended by the speaker. The speaker does not have uncertainty with respect to what actually holds.	*"There's an Oatio here, or actually, there's a wheat here."*

Function	Definitions	Examples
Conditionals	Explaining in the second coordinand, what would follow if the first coordinand is (or is not) followed. Subtype of Directive.	*"Put that out of your mouth, or I'm gonna put it away."* – *"Come over here and I'll show you."*
Unconditionals	Denying the dependence of something on a set of conditions. Typical format: "Whether X or Y, Z". Subtype of Descriptions.	*"Ready or not, here I come!"* (playing hide and seek)

Table 9

Definitions of answer types and their examples.

Type	Definitions	Examples
No Answer	The child provides no answer to the question.	Mother: *"Would you like to eat some applesauce or some carrots?"* Child: *"Guess what Max!"*
YN	The child responds with *yes* or *no*.	Father: *"Can I finish eating one or two more bites of my cereal?"* Child: *"No."*
AB	The child responds with one of the disjuncts (alternatives).	Mother: *"Is she a baby elephant or is she a toddler elephant?"* Child: *"It's a baby. She has a tail."*

Inter-annotator agreement

Figure 15 shows the percentage agreement and the kappa values for each annotation category over the 8 iterations.

Agreement in the following three categories showed substantial improvement after better and more precise definitions and annotation criteria were developed: connective interpretation, intonation, and communicative function. First, connective interpretation showed major improvements after annotators developed more precise criteria for selecting the propositions under discussion and separately wrote down the two propositions connected by the connective word. For example, if the original utterance was "do you want milk or juice?", the annotators wrote "you want milk, you want juice" as the two propositions under discussion. This exercise clarified the exact propositions under discussion and sharpened annotator intuitions with respect to the connective interpretation that is communicated by the utterance. Second, annotators improved agreement on intonation by reconstructing an utterance's intonation for all three intonation categories. For example, the annotator would examine the same sentence "do you want coffee or tea?" with a rise-fall, a rise, and a flat intonation. Then the annotator would listen to the actual utterance and see which one most resembled the actual utterance. This method helped annotators judge the intonation of an utterance more accurately. Finally, agreement on communicative functions improved as the definitions were made more precise. For example, the definition of "directives" in Table 8 explicitly mentions the difference between "directives" and "options". Clarifying the definitions of communicative functions helped improve annotator agreement.

Inter-annotator reliability for conjunction was calculated in the same way. Two different annotators coded 300 utterances of *and*. Inter-annotator reliability was calculated over 10 iterations of 30 examples. Figure 16 shows the percentage agreement between the annotators as well as the kappa values for each iteration. Despite high percentage agreement between annotators, the kappa values did not pass the set threshold of 0.7 in three consecutive iterations. This paradoxical result is mainly due to a property of kappa. An imbalance in the prevalence of annotation categories can drastically lower its value. When one category is extremely common with high agreement while other categories are rare, kappa will be low (Cicchetti & Feinstein, 1990; Feinstein & Cicchetti, 1990). In almost all annotated categories for conjunction, there was one class that was extremely prevalent. In such cases, it is more informative to look at the class specific agreement for the prevalent category than the overall agreement measured by Kappa (Cicchetti & Feinstein, 1990; Feinstein & Cicchetti, 1990).

Table 10 lists the dominant classes as well as their prevalence, the values of class specific agreement index, and category agreement index (Kappa). Class specific agreement index is defined as $2n_{ii}/n_{i.} + n_{.i}$, where i represents the class's row/column number in the category's confusion matrix, n the number of annotations in a cell, and the dot ranges over all the row/column numbers (Fleiss, Levin, & Paik, 2013, p. 600; Ubersax, 2009). The class specific agreement indices are high for all the most prevalent classes showing that the annotators had very high agreement on these class, even though the general agreement index (Kappa) was often low. The most extreme case is the category "consistency" where almost all instances were annotated as "consistent" with perfect class specific agreement but low overall Kappa. In the case of utterance type and syntactic level where the distribution of instances across classes was more even, the general index of agreement Kappa is also high. In general, examples of conjunction showed little variability across annotation categories and mostly fell into one class within each category. Annotators had high agreement for these dominant classes.

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Table 10

Most prevalent annotation class in each annotation category with the values of class agreement indeces and category agreement indeces (Kappa).

Annotation Category	Class	Prevalence	Class Agreement Index	Kappa
intonation	flat	0.86	0.89	0.24
interpretation	AND	0.96	0.98	0.39
answer	NA	0.84	0.94	0.67
utterance_type	declarative	0.76	0.94	0.70
communicative_function	description	0.77	0.90	0.59
syntactic_level	clausal	0.67	0.91	0.70
consistency	consistent	0.99	1.00	0.50

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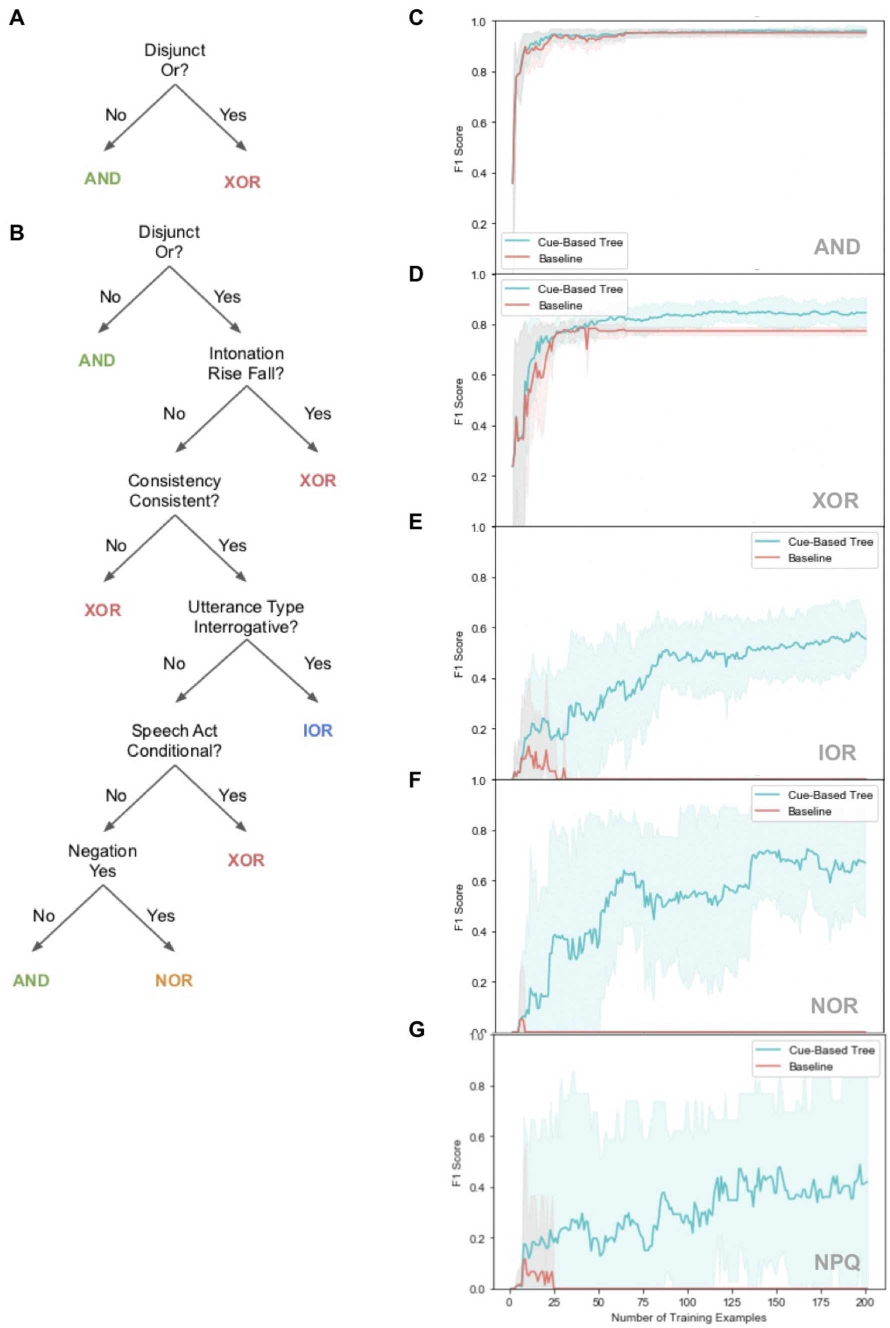

Figure 14. (A) The structure for the baseline (highest gini threshold, 0.2) decision tree trained on examples with XOR, IOR, AND, and NOR interpretations. (B) The structure for the cue-based decision tree (low gini threshold of 0.01). The average F1 score with 95% confidence intervals as a function of the number of training examples in the baseline and cue-based model when treating as positive (C) AND, (D) XOR, (E) IOR, (F) NOR respectively.

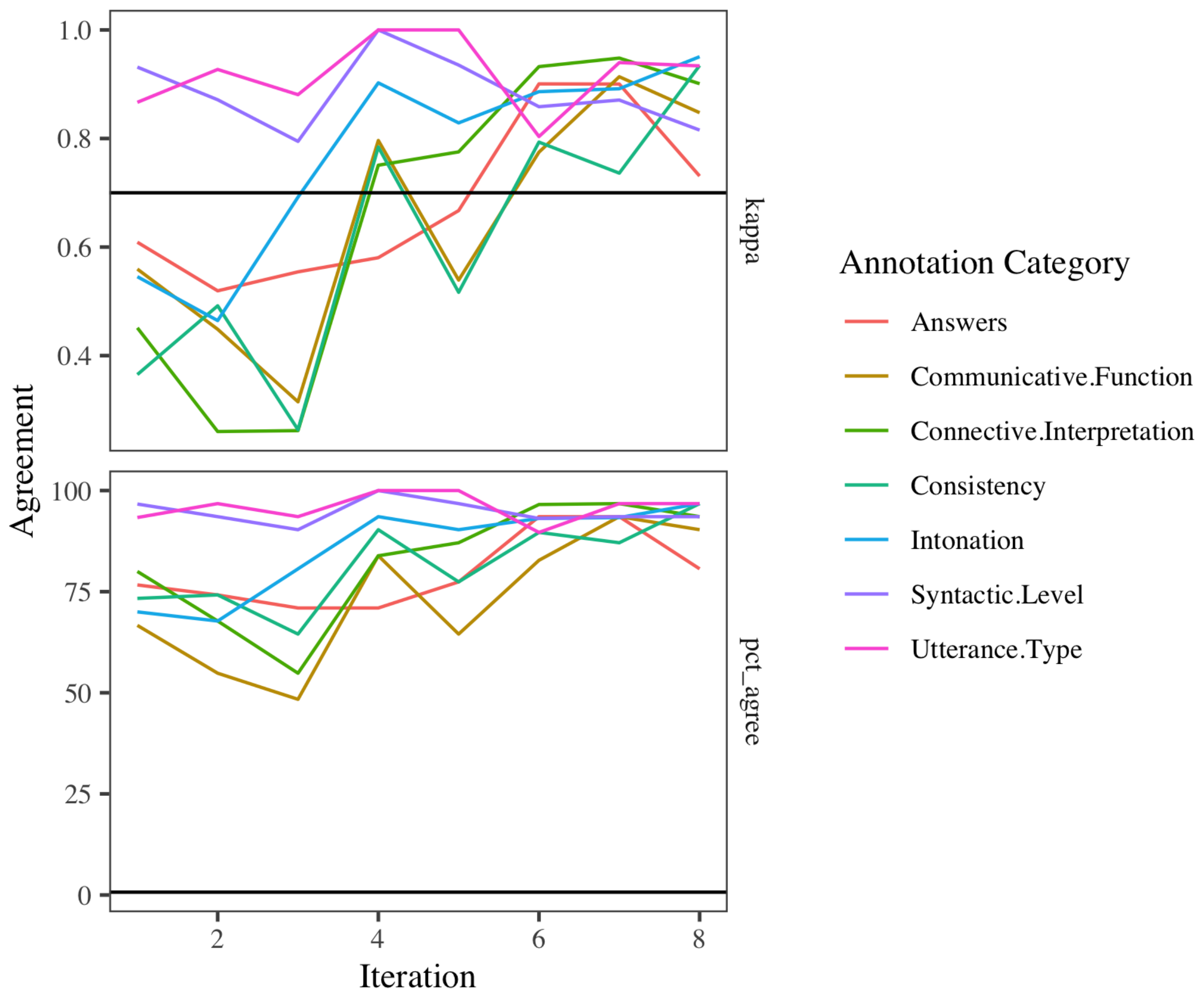

Figure 15. Inter-annotator agreement for disjunction examples.

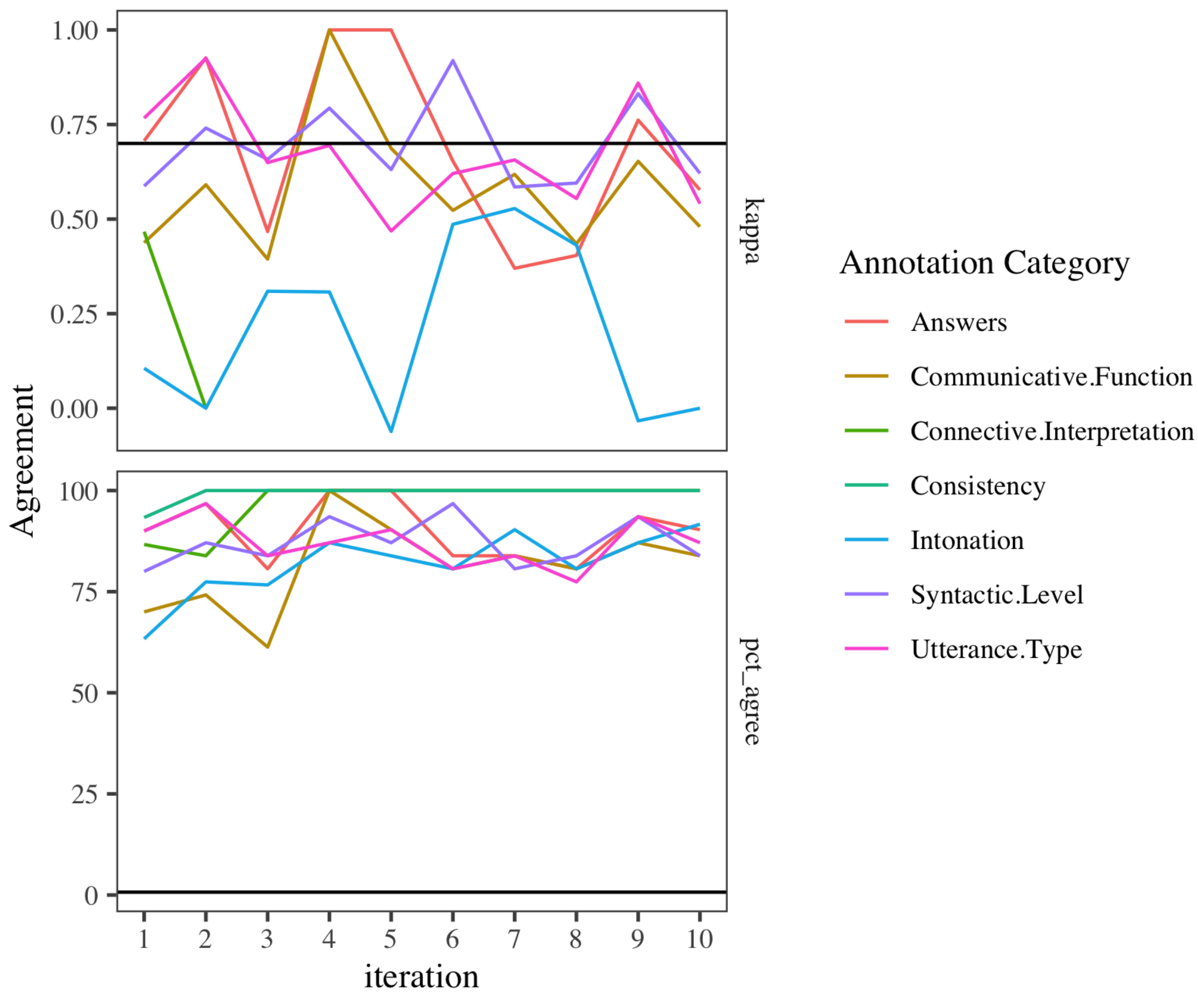

Figure 16. Inter-annotator agreement for conjunction examples.